

The Carver-Greenfield Process
Dehydro-Tech Corporation
Applications Analysis Report

Risk Reduction Engineering Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268



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Notice

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Foreword

The Superfund Innovative Technology Evaluation (SITE) Program was authorized in the 1986 Superfund Amendments and Reauthorization Act. The program is administered by the U.S. Environmental Protection Agency (EPA) Office of Research and Development. The purpose of the program is to accelerate the development and use of innovative cleanup technologies applicable to Superfund and other hazardous waste sites. This is accomplished through technology demonstrations designed to provide performance and cost data on selected technologies.

A field demonstration was conducted under the SITE Program to evaluate the Carver-Greenfield Process, developed by Dehydro-Tech Corporation. The demonstration was conducted at the Risk Reduction Engineering Laboratory's Releases Control Branch facility in Edison, New Jersey. The demonstration effort assessed the technology's ability to treat hazardous wastes based on performance and cost. Documentation consists of two reports: (1) a Technology Evaluation Report, which describes the field activities and laboratory results and (2) this Applications Analysis Report, which interprets the data and discusses the potential applicability of the technology.

A limited number of copies of this report will be available at no charge from EPA's Center for Environmental Research Information, 26 West Martin Luther King Drive, Cincinnati, Ohio, 45268. Requests should include the EPA document number found on the report's cover. When the limited supply is exhausted, additional copies can be purchased from the National Technical Information Service, Ravensworth Building, Springfield, Virginia, 22161, 703/487-4600. Reference copies will be available at EPA libraries in the Hazardous Waste Collection. To inquire about the availability of other reports, call the SITE Clearinghouse hotline at 800/424-9346 or 202/382-3000 in Washington, D.C.

E. Timothy Oppelt, Director

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Abstract

This report evaluates the Dehydro- Tech Corporation's Carver-Greenfield (C-G) Process and focuses on the technology's ability to separate waste mixtures into their constituent solid, organic, and water fractions while producing a solid residual that meets applicable disposal requirements. This report presents performance and economic data from the U.S. Environmental Protection Agency Superfund Innovative Technology Evaluation (SITE) demonstration and three case studies.

The C-G Process separates hazardous solvent-soluble organic contaminants (indigenous oil) from sludges, soils, and industrial wastes. The process involves adding waste to a solvent which extracts hazardous organics from contaminated solid particles and concentrates them in the solvent phase. In most applications, a food-grade hydrocarbon with a boiling point of about 400 °F is used as the solvent. Typically, 5 to 10 lb of solvent per lb of solids are used. First, the waste is added to the solvent in a mixing tank. The mixture is then transferred to a high-efficiency evaporator where the water is removed by vaporization. Next, the dry mixture is fed to a device that separates the solvent from the solid particles. Subsequent extractions of the dry solids may be made with clean recycled solvent. After final separation by centrifuging, any residual solvent is removed by hydroextraction, adesolventizing process that uses hot nitrogen gas or steam to separate the solvent from the solids. The final solids product typically contains low percentages of water (<5 %) and solvent (< 1%). In the full-scale system, spent solvent containing indigenous oil is distilled to separate the indigenous oil from the solvent. The solvent is subsequently reused in the process. Products from the process include (1) clean dry solids, (2) a water product virtually free of solids and indigenous oil, and solvent and (3) extracted solvent-soluble compounds (indigenous oil).

The C-G Process demonstration was conducted as a part of the SITE Program at the Risk Reduction Engineering Laboratory's Releases Control Branch facility in Edison, New Jersey, using drilling mud waste from the PAB Oil Superfund site in Abbeville, LA. During the demonstration, the C-G Process pilot plant experienced no major operational problems. During startup and shakedown, the system exhibited minor, repairable problems.

The system generated a treated solids product that passed Toxicity Characteristic Leaching Procedure (TCLP) criteria for volatiles, semivolatiles, and metals. The system successfully separated the feed stream into its constituent water, indigenous oil, and solids fractions, and produced a dry final solids product containing less than 1% solvent.

Potential wastes that might be treated by this technology include industrial residues, Resource Conservation and Recovery Act wastes, Superfund wastes, and other wastes contaminated with organic compounds. The technology is especially applicable to wastes with high water content. A brief overview of the results from the C-G Process case studies, which discuss wastes treated by the technology, is presented in Appendix D.

Economic data indicate that the cost of treating wastes similar to those treated in SITE demonstration, including disposal of residuals, is about \$523 per wet ton of feed, of which \$221 is C-G Process technology-specific and \$302 is site-specific. Of the \$302 per ton site-specific cost, about \$240 per ton is for the incineration of indigenous oil separated from the feed.

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Abbreviations and Symbols

ARAR	Applicable or relevant and appropriate requirements
BOD	Biochemical Oxygen Demand
Btu	British thermal unit
Btu/lb	Btu per pound
CAA	Clean Air Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
C-G	Carver-Greenfield
COD	Chemical Oxygen Demand
CWA	Clean Water Act
DOT	U.S. Department of Transportation
DTC	Dehydro-Tech Corporation
EPA	U.S. Environmental Protection Agency
FR	Federal Register
g	Gram
H₂O	Water
hr	Hour
kg	Kilogram
L	Liter
LDR	Land Disposal Restrictions
lb	Pound
lb/hr	Lb per hour
mg	Milligram
mg/L	Mg per liter
N₂	Nitrogen
NPDES	National Pollutant Discharge Elimination System
ORD	EPA Office of Research and Development
OSHA	U.S. Occupational Safety and Health Administration
Pb	Lead
PCB	Polychlorinated biphenyl
POTW	Publicly Owned Treatment Works
ppm	Parts per million
psi	Pounds per square inch

QA	Quality assurance
QC	Quality control
RCRA	Resource Conservation and Recovery Act
RFP	Request for proposal
SARA	Superfund Amendments and Reauthorization Act
scf	Standard cubic feet
SCFH	Standard cubic feet per hour
SDWA	Safe Drinking Water Act
sec	Second
SITE	Superfund Innovative Technology Evaluation
s o w	Solids/Oil/Water Analysis
SSM	Synthetic Soil Matrix
SVOC	Semivolatile organic compound
TCLP	Toxicity Characteristic Leaching Procedure
TPH	Total Petroleum Hydrocarbons
TSCA	Toxic Substances Control Act
µg	Microgram
VOC	Volatile organic compound
wt	Weight

Acknowledgments

This report was prepared under the direction and coordination of Laurel Staley, U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) Project Manager at the Risk Reduction Engineering Laboratory, Cincinnati, Ohio.

This report was prepared for EPA's SITE program by Thomas Raptis, Deidre Knodell, and Ken Partymiller of PRC Environmental Management, Inc., and Karl Scheible, Gary Grey, and Ashok Gupta of HydroQual, Inc. PRC and HydroQual performed the process sampling; and General Testing Corporation performed the chemical analyses for this SITE demonstration.

Section 1

Executive Summary

1.1 Background

In 1986, the U.S. Environmental Protection Agency (EPA) established the Superfund Innovative Technology Evaluation (SITE) Program to promote the development and use of innovative technologies to remediate Superfund sites. Technologies in the SITE Program are analyzed in two documents, the Technology Evaluation Report and this Applications Analysis Report. The Applications Analysis Report evaluates the applicability and estimates the costs of the Dehydro-Tech Corporation's (DTC) Carver-Greenfield (C-G) Process based on available data. Data not generated from the SITE demonstration were obtained from DTC, the technology developer. DTC's data are based on 25 years of commercial-scale operations of the C-G **Process™** treating nonhazardous municipal and industrial wastes.

The C-G Process was evaluated under EPA's SITE Program, based on a Demonstration Plan agreed to by EPA and the developer. The demonstration was conducted at an EPA research facility in Edison, NJ, in August 1991, using drilling mud waste from the PAB Oil and Chemical Services (PAB Oil) Superfund site in Abbeville, LA.

The primary objectives of the C-G SITE demonstration included the following:

- To assess how well the C-G Process effectively separates petroleum-based hydrocarbon contaminated drilling mud wastes into their constituent solid, oil and water fractions
- To evaluate the C-G Process's reliability
- To develop overall economic data on the C-G Process

Secondary objectives included the following:

- To assess the ability of the C-G Process to remove volatile and semivolatile organic contaminants and metals from solids
- To document the operating conditions of the C-G Process for application to hazardous waste sites

- * To characterize residuals (water, oil, and solids) relative to applicable standards for final disposal or further treatment

This report provides information based on the results from the SITE demonstration and related case studies; this information is necessary if the C-G Process technology is to be considered for use on Superfund and Resource Conservation and Recovery Act (RCRA) hazardous waste sites. Section 2 of this report presents an overview of the SITE Program, explains how SITE Program results are documented, and lists key contacts. Section 3 discusses the SITE demonstration objectives and describes the C-G Process technology. It also briefly describes the demonstration and its findings regarding the technology's application, including potentially applicable environmental regulations, the effects of waste characteristics and operating parameters on technology performance, material handling requirements, community impact, and personnel issues. Section 4 summarizes the costs of implementing the technology. Appendices A through D include the following: 1) a detailed description of the C-G Process, 2) DTC's claims regarding the technology, 3) a summary of the SITE demonstration results, and 4) information from case studies prepared by DTC.

1.2 Overview of the SITE Demonstration

The C-G Process was demonstrated at an EPA research facility in Edison, NJ in August 1991. About 640 lb of drilling mud waste was treated during all phases of testing. Drilling mud, a material that circulates around drilling augers during oil production activities, consists of oils, solids, and water and is difficult to separate using conventional techniques such as sedimentation. As a result, many Superfund sites in oil-producing states are contaminated by drilling muds similar to those at the PAB Oil site.

The drilling mud waste at the PAB Oil site was excavated, passed through a 1/4-in. screen, collected in five 55-gal drums, and shipped to EPA's Edison, NJ facility. The demonstration of the C-G Process included a series of shakedown runs to establish optimal operating conditions, a blank run with no waste treatment, and two test runs.

Extensive process operating data and numerous liquid and solid samples were collected for analysis. Operating data were monitored and recorded, including raw waste feed rate,

nitrogen consumption rates, electrical consumption, and temperatures and pressures throughout the system.

Laboratory analyses included analyses of the raw feed and solids product for Solids/Indigenous Oil/Water (SOW) content, a measure of the C-G Process's separation efficiency. This test uses an extraction procedure to quantify the percentage of solids, indigenous oil, and water in untreated and treated samples. Solids effluent samples were also analyzed for Toxicity Characteristic Leaching Procedure (TCLP) criteria. Water effluent samples were analyzed for organics and metals content. Analytical data are summarized in Section 3.3 and given in greater detail in Appendix C.

1.3 Waste Applicability

The C-G Process can treat wastes containing water and organic contaminants. Commercial C-G Process plants have treated materials with high water contents, such as meat rendering waste, municipal sewage sludge, paper mill sludge, brewery treatment plant sludge, pharmaceutical plant waste, and leather dyeing waste. Because the process uses a dewatering technology, it can treat waste streams containing up to 99% water. The C-G Process can treat wastes with solvent-soluble contents ranging from parts per million (ppm) levels up to 75%. Since the system cannot process large particles, a grinder can be used to reduce the size of influent solids to a maximum particle size of about 1/4 in.

1.4 Economics

An economic analysis was performed on 12 separate cost categories. Because this analysis is based on a C-G Process unit not yet constructed, the costs presented are order-of-magnitude estimates (-30% to +50%). Cost estimates are based on using a C-G Process unit with a feed capacity of 1.4 tons/hr. Based on the assumptions made in the economic analysis, the estimated cost per wet ton for treating drilling mud waste at a site similar to the PAB Oil site is \$527, of which \$225 per ton is technology-specific and \$302 per ton is site-specific. However, these figures depend on the quantity of waste to be treated and the level of treatment required. Also, factors such as residual transportation and disposal costs can vary greatly depending on specific site and waste characteristics.

1.5 Results from the SITE Demonstration

The following overall conclusions about the Carver-Greenfield Process technology are drawn from the results of the SITE demonstration.

- 1) The Carver-Greenfield Process separated a petroleum oil-contaminated waste drilling mud into its solids, oil, and water phases. The C-G Process removed about 90% of the indigenous oil (as measured by SOW). No detectable levels of indigenous total petroleum hydrocarbons (TPH) were found on the solids product from both test runs.
- 2) The final solids product from the demonstration is a dry powder similar in character to dry bentonite. Isopar-L solvent, a food grade oil, comprises the bulk of the residual oil content on the final solids product.
- 3) Values for all metals and organics are well below the RCRA Toxicity Characteristic Leaching Procedure (TCLP) limits for characteristic hazardous wastes. Additionally, the indigenous TPH concentrations were reduced to trace levels on the final solids product. Residues from the C-G Process may still require disposal as hazardous materials, due to the regulatory constraints governing the disposal of Superfund wastes.
- 4) The C-G Process, as demonstrated on the PAB Oil site wastes, does not remove metals bound to the solids phase. The process may increase the apparent metals concentration in the solids fraction by volume reduction.
- 5) The resulting water product requires further treatment due to the presence of light organics and solvent. In some cases, the wastewater may be disposed of at a local publicly owned treatment works (POTW).
- 6) A full-scale C-G Process system can process drilling mud waste from the PAB Oil site at an estimated cost of \$523 per wet ton of feed. Of this total, \$221 is C-G Process technology-specific, and \$302 is site-specific. Of the \$302 per ton site-specific cost, about \$240 is for the incineration of indigenous oil separated from the feed. Treatment costs are highly site-specific, and accurate cost estimation requires data from a site remedial investigation or waste profile, as well as specific treatment goals. Variability in the waste characteristics or pretreatment requirements could significantly affect treatment costs.

Dehydro-Tech has prepared an independent cost analysis of the Carver-Greenfield Process. It appears in Appendix B.

Section 2

Introduction

This section provides background information about EPA's SITE Program and discusses the purpose of the Applications Analysis Report. It also briefly describes the C-G Process. Appendix A describes the C-G Process in detail. For additional information about the SITE Program and the C-G Process technology contact the individuals listed at the end of this section.

2.1 Purpose, History, and Goals of the SITE Program

EPA's SITE Program is dedicated to advancing the development, evaluation, and implementation of innovative treatment technologies applicable to hazardous wastes and hazardous waste sites. The SITE Program was established in response to the 1986 Superfund Amendments and Reauthorization Act (SARA), which recognized a need for an alternative or innovative treatment technology research and development program. The SITE Program is administered by EPA's Office of Research and Development (ORD).

The SITE Program's major goals are the following:

- * To identify and remove impediments to the development and use of alternative technologies
- * To demonstrate promising innovative technologies and establish reliable performance and cost information for site characterization and cleanup
- * To develop procedures and policies that encourage selection of alternative treatment remedies at Superfund sites
- * To provide a development program that nurtures emerging technologies

The SITE Program consists of four component programs: (1) Demonstration Program, (2) Emerging Technology Program, (3) Measurement and Monitoring Technologies Development Program, and (4) Technology Information Services. This document was produced as part of the Demonstration Program. The SITE Demonstration Program's objective is to develop reliable performance and cost data on innovative technologies so that potential users can assess whether a technology might apply to specific sites.

Demonstration data are used to assess the performance of the technology, the potential need for pretreatment and post-treatment processing of the waste, applicable types of waste and media, potential operating problems, and approximate capital and operating costs. Demonstration data can also provide insight into long-term operating and maintenance costs and long-term risks.

ORD selects technologies for the SITE Demonstration Program through annual requests for proposals (RFP). ORD staff reviews proposals to determine the technologies with the most promise for use. To be eligible, technologies must be at the pilot- or full-scale stage, must be innovative, and must offer some advantage over existing technologies. Mobile technologies are of particular interest. Cooperative agreements between EPA and the developer set forth responsibilities for conducting the demonstration and evaluating the technology. The developer is responsible for demonstrating the technology at the selected location and paying costs to transport, operate, and remove equipment. EPA is responsible for project planning, site preparation, sampling and analysis, quality assurance (QA) and quality control (QC), preparing reports, disseminating information, and transporting and disposing of treated waste materials.

Each SITE demonstration evaluates a technology's performance in treating a particular waste. To obtain data with broad applications, attempts are made to select waste frequently found at other contaminated sites. However, because the waste at other sites usually differs from the tested waste, a successful demonstration does not ensure that the technology will work equally well at other sites. Demonstration data may have to be extrapolated using other information about the technology to estimate the total operating range in which the technology will perform satisfactorily.

The amount of data available to evaluate a technology varies widely. Data may be limited to laboratory tests on synthetic wastes or may include performance data on actual wastes treated by a pilot-scale treatment system. In addition, limited conclusions can be drawn from a single field demonstration. A successful field demonstration does not ensure that a technology will be widely applicable or fully developed on a commercial scale.

2.2 Documentation of the SITE Demonstration Results

EPA publishes the results of each SITE demonstration in two documents: (1) a Technology Evaluation Report and (2) an Applications Analysis Report.

2.2.1 Technology Evaluation Report

The Technology Evaluation Report provides a comprehensive description of the demonstration and its results. It is intended for engineers and others making a detailed evaluation of the technology for a specific site and waste. Readers should gain a detailed understanding of the technology's performance and of the technology's advantages, risks, and costs for a given application. This information helps to make preliminary cost estimates for the technology. This information also aids potential users of the technology.

2.2.2 Applications Analysis Report

The Applications Analysis Report assists in evaluating whether a specific technology should be considered further for a particular cleanup situation. It is intended for those responsible for implementing specific remedial actions. The report discusses advantages, disadvantages, and limitations of the technology. Costs for different applications are estimated based on data for pilot- and full-scale operations. The report also discusses factors affecting performance and cost, such as site and waste characteristics.

EPA encourages use of demonstrated technologies by providing information on a technology's applicability to cer-

tain sites and wastes and on the costs of these applications. The Applications Analysis Report draws reasonable conclusions about a technology's broad-range applicability, and is therefore useful to those considering a technology for hazardous site cleanups. The report represents a critical step in the development and commercialization of a treatment technology.

2.3 Technology Description

The C-G Process separates hazardous solvent-soluble organic contaminants (indigenous oil) from, sludges, soils, and industrial wastes. The process involves adding waste to a solvent which extracts hazardous organics from contaminated solid particles and concentrates them in the solvent phase. In most applications, a food-grade hydrocarbon with a boiling point of about 400 °F is used as the solvent. Typically, 5 to 10 lb of solvent per lb of solids are used. First, the waste is added to the solvent in a mixing tank (see Figure 2-1). The mixture is then transferred to a high-efficiency evaporator where the water is removed by vaporization. Next, the dry mixture is fed to a device that separates the solvent from the solid particles. Subsequent extractions of the dry solids may be made with clean recycled solvent. After final separation by centrifuging, any residual solvent is removed by hydroextraction, a desolventizing process that uses hot nitrogen gas or steam to separate the solvent from the solids. The final solids product typically contains low percentages of water (<5%) and solvent (<1%). In the full-scale system, spent solvent containing indigenous oil is distilled to separate the indigenous oil from the solvent. The solvent is subsequently reused in the process. Products from the process include (1) clean dry solids; (2) a water product virtually free of solids,

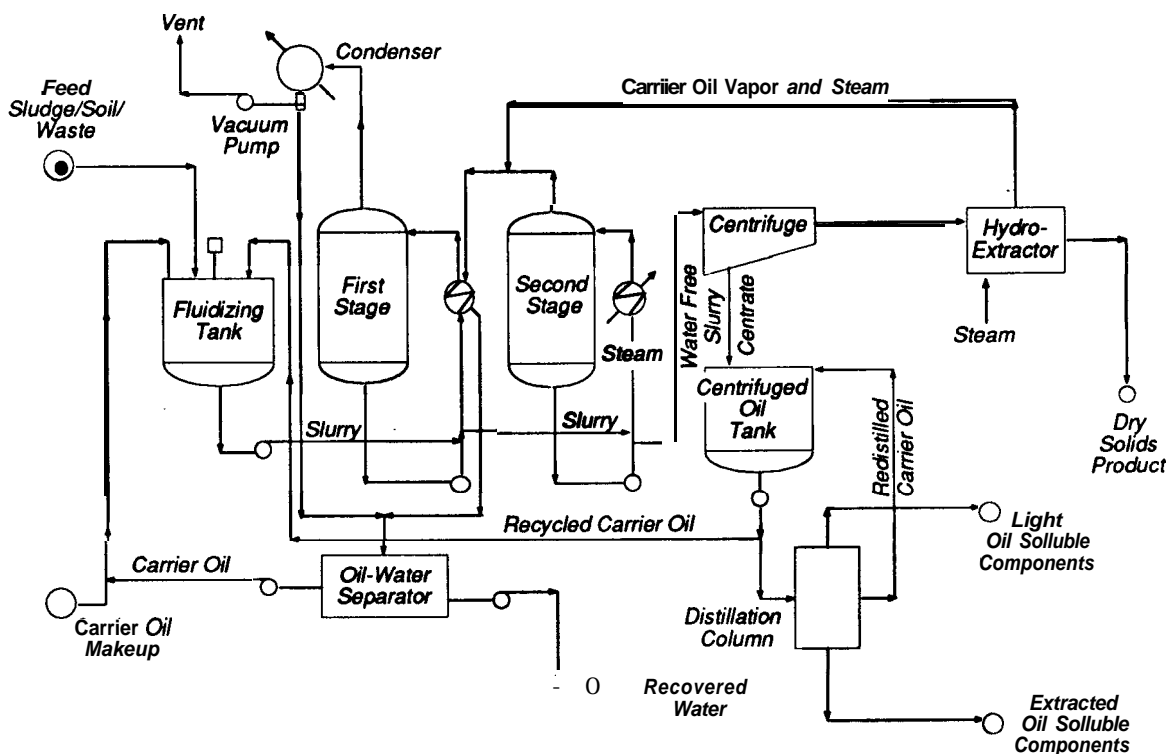


Figure2-1. Simplified Process Flow Diagram — The Carver-Greenfield Process.

indigenous oil, and solvent; and (3) extracted solvent-soluble compounds (indigenous oil). Note that Figure 2-1 refers to the extraction solvent as carrier oil.

2.4 Key Contacts

Additional information on the Carver-Greenfield Process technology and the SITE Program can be obtained from the following sources:

1. Vendor concerning the process:

Thomas C. Holcombe
President
Dehydro-Tech Corporation

6 Great Meadow Lane
E. Hanover, NJ 07936
201/887-2182
FAX 201/887-2548

2. EPA Project Manager concerning the SITE Demonstration:

Laurel Staley
U.S. EPA - ORD
Risk Reduction Engineering Laboratory
26 West Martin Luther King Drive
Cincinnati, OH 45268
5 13/569-7863
FAX 5 13/569-7620

Section 3

Technology Applications Analysis

3.1 Introduction

This section assesses the ability of the Carver-Greenfield (C-G) Process to treat drilling mud wastes similar to waste excavated from the PAB Oil site. This assessment is based on the results of the SITE demonstration and on data supplied by the technology developer, DTC. Because the results of the demonstration are of known quality, conclusions are drawn mainly from the demonstration results, which are summarized in Appendix C of this report and presented in detail in the Technology Evaluation Report (U.S. EPA, 1992). Case studies supplied by DTC are presented in Appendix D.

The C-G Process is a patented drying and extraction process designed to treat wastes containing solids, water, and organics. During processing, the waste feed is fluidized with a hydrocarbon-based solvent to extract soluble organic materials from the solids into the solvent phase. Water is then removed from the slurry by evaporation, and the slurry is centrifuged to separate the solids from the solvent. The solids are processed in a desolventizer. This unit operation removes residual solvent by evaporation and stripping by countercurrent contacting of solids with a stripping gas, such as nitrogen. In full-scale commercial operations, the used solvent, which contains dissolved organics indigenous to the waste, undergoes fractional distillation to recover the solvent and separate the lighter and heavier indigenous organic components extracted from the waste. The recovered solvent is recycled to the fluidization operation, and the extracted light and heavy indigenous organic fractions are disposed of.

The dry solids product produced during the demonstration did not leach metals, volatile organic compounds (VOC), or semivolatile organic compounds (SVOC) above the RCRA regulatory limits. Therefore, if similar TCLP results are obtained in a full-scale remediation, the effluent solids can be recycled as clean fill material or disposed of in a sanitary landfill if the waste feed is not a RCRA-listed hazardous waste. If the waste feed is a listed waste, it must be delisted prior to disposal.

3.2 SITE Demonstration Objectives

The primary objectives of the C-G Process SITE demonstration included the following:

- * To assess how well the C-G Process effectively separates petroleum-based hydrocarbon contaminated drilling mud wastes into their constituent solid, oil, and water fractions
- * To evaluate the C-G Process's reliability
- * To develop overall economic data on the C-G Process

Secondary objectives included the following:

- * To assess the ability of the C-G Process to remove volatile and semivolatile organic contaminants and metals from solids
- * To document the operating conditions of the CG Process for application to hazardous waste sites
- * To characterize residuals (water, oil, and solids) relative to applicable standards for final disposal or further treatment

3.3 Summary of the SITE Demonstration

In August 1991, the C-G Process was demonstrated using about 640 lb of drilling mud waste at a U.S. EPA research facility in Edison, NJ. Although not considered a RCRA hazardous waste, the drilling mud waste contains significant quantities of indigenous oil and elevated levels of heavy metals that could potentially leach into the environment. The drilling mud waste was shipped to U.S. EPA in Edison, NJ from the PAB Oil site in Abbeville, LA.

The C-G Process unit used in the demonstration was a pilot-scale, trailer-mounted unit, capable of treating about 100 lb/hr of waste from the PAB Oil site. The demonstration consisted of several shakedown runs to establish operating conditions, followed by a blank run and two test runs using the drilling mud as waste feed. The shakedown runs, conducted in July and August 1991, evaluated start-up and operating conditions, feed rates, operating temperatures, nitrogen flow rates, and other parameters.

After the shakedown runs were completed, DTC began the blank run. Several problems were encountered during the initial attempts to complete the blank run. The free water in the silt/water feed produced a gummy material unsuitable for processing, due to the potential for plugging problems. This

problem is usually remedied in commercial operations by adding a surfactant or dry treated solids to the waste feed.

Adding a surfactant produces a stable solids suspension in the solvent for feedstocks containing free water. During the initial blank run attempt, however, the SOW procedure detected the surfactant chosen for start-up as indigenous oil at unacceptable levels. Therefore, this approach was abandoned due to the potential to produce an unsatisfactory solids product.

The other alternative, used in some commercial operations, is to "add-back" dry treated solids to the solvent before waste is added. A modification of this technique was used in the C-G Process demonstration, by which commercial dry bentonite, a typical drilling mud component, was added to recirculating solvent in the evaporator section. Drilling mud waste was then added to this recirculating stream during evaporation. Use of this technique during the demonstration caused free water to be absorbed and evaporated, thus preventing plugging.

Each test run consisted of three individual batch extractions. During the test runs, about 640 lb of drilling muds were processed. Three runs were originally scheduled, but Run 3 was canceled due to scheduling limitations imposed by EPA Region 2.

Tables 3-1 and 3-2 present average sample results for all sample locations and parameters. Headings labeled A, B, and C in the tables indicate the first, second, and third extractions, respectively, for each test run. Refer to Appendix C for the data used to develop Tables 3-1 and 3-2, as well as detailed sampling location information.

Assessing the solids/oil/water separation efficiency of the C-G Process was one of the primary objectives of the demonstration. Separation efficiency is based primarily on how well the process removes oil indigenous to the waste. As discussed in Appendix C, the indigenous oil consists of total petroleum hydrocarbons (TPH), as well as other material detected as oil by the SOW procedure. The SOW procedure is essentially a toluene extraction, while TPH utilizes silica gel. These other materials may be polar organics or surfactants, which are soluble in toluene (SOW procedure) but are retained on silica gel (TPH procedure). Since TPH is the most commonly regulated parameter for oil content, oil removal is expressed in terms of a new parameter, indigenous TPH. Indigenous TPH removal is defined as feed TPH minus final product TPH minus final product Isopar-L content. On a percentage basis, indigenous TPH removal is the above quantity (times 100) divided by the initial feed TPH. This calculation must be made because Isopar-L solvent, a food grade oil not present in the waste, is detected in the TPH procedure. This is discussed in more detail in Appendix C and in the Technology Evaluation Report (U.S. EPA, 1992). Table 3-3 presents estimated indigenous oil and indigenous TPH removal efficiencies. Indigenous oil removal is also shown graphically in Figures 3-1 and 3-2.

Indigenous oil removals are lower than indigenous TPH removals because toluene-soluble organics in the SOW procedure

are not detected in the TPH procedure. Indigenous TPH removal was essentially 100% for both test runs.

Barium and silver were the only TCLP materials detected. Appendix C presents a complete summary of the TCLP results. Silver was present at concentrations slightly above the detection limit in the final product of the second test run. Barium results were significantly below the regulatory limit of 100 mg/l. However, TCLP concentrations may increase due to the way in which the process concentrates solids. When solids increase from 50% in the feedstock to 98% in the final product, a proportional increase in the TCLP extract should be expected due to volume reduction. There is no evidence, however, that actual leachability of metals is increased by the process.

3.4 Conclusions

The following overall conclusions about the C-G Process are drawn from the results of the SITE demonstration.

- 1) The C-G Process separated a petroleum oil-contaminated waste drilling mud into its solids, oil, and water phases. The C-G Process removed about 90% of the indigenous oil (as measured by SOW). No detectable levels of indigenous TPH were found on the solids product from both test runs.
- 2) The final solids product from the demonstration is a dry powder similar in character to dry bentonite. Isopar-L solvent, a food grade oil, comprises the bulk of the residual oil content on the final solids product.
- 3) Values for all metals and organics are well below the RCRA TCLP limits for characteristic hazardous wastes. Additionally, the indigenous TPH concentrations were reduced to trace levels on the final solids product. Residues from the C-G Process may still require disposal as hazardous materials, due to the regulatory constraints governing the disposal of Superfund wastes.
- 4) The C-G Process, as demonstrated on the PAB Oil site wastes, does not remove metals bound to the solids phase. The process may increase the apparent metals concentration in the solids fraction by volume reduction.

3.5 Potential Regulatory Requirements

This subsection discusses specific environmental regulations pertinent to the transport, treatment, storage, and disposal of wastes generated during the operation of the C-G Process system. The regulations that apply to a particular remediation activity will depend on the type of remediation site and the type of waste being treated.

3.5.1 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)

CERCLA, as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986, provides for federal authority to respond to releases of hazardous substances, pollutants, or contaminants to air, water, and land (Federal

Table 3-1 Carver- Greenfield Process Averages, Test Run 1

Parameters	Units	Feed-Stock	Slurried Feedstock			Centrate			Centrifuge Cake			Final Products		
			A	B	C	A	B	C	A	B	C	Treated Solids	Cond. Water	Cond. Solvent
V O C														
toluene	(wet wt)	546	N A	NA	NA	N A	N A	NA	NA	NA	NA	NA	<250	N A
ethylbenzene		993	N A	NA	NA	N A	N A	NA	NA	NA	NA	NA	<250	N A
total xylene (o,m,p)		3658	N A	NA	NA	N A	N A	NA	NA	NA	NA	NA	<250	N A
acetone		N D	N A	NA	NA	N A	N A	NA	NA	NA	NA	NA	4927	N A
2-butanone (MEK)		N D	N A	NA	NA	N A	N A	NA	NA	NA	NA	NA	1067	N A
SVOC - acid extractables (µg/kg)														
phenol	(wet wt)	<100000	N A	NA	NA	N A	NA	NA	NA	N A	N A	<660	<203	N A
SVOC - base neutral extractables (µg/kg)														
phenanthrene	(wet wt)	15950	N A	NA	NA	N A	N A	NA	NA	NA	NA	2 5 7	<250	N A
2-methyl naphthalene		<26183	N A	NA	NA	N A	N A	NA	NA	N A	N A	<660	<500	N A
isophorone		<50000	N A	NA	NA	N A	N A	NA	NA	NA	NA	<364	<250	N A
bis(2-ethylhexyl) phthalate		<50000	N A	NA	NA	N A	N A	NA	NA	NA	NA	5 9 2	<250	N A
di-n-octyl phthalate		<50000	N A	NA	NA	N A	N A	NA	NA	NA	NA	<321	<250	N A
Metals (µg/g)														
aluminum	(wet wt)	10663	N A	NA	NA	24.4	3452	791	NA	N A	N A	16833	261	11.43
antimony		<5.0	NA	NA	NA	<5.0	<5.0	<5.0	NA	NA	NA	<5.0	<0.052	<5.0
barium		2990	N A	NA	NA	7.3	904.6	10.9	NA	N A	N A	3193	0.0382	<0.50
beryllium		0.831	N A	NA	NA	<0.50	<0.50	<0.50	N A	N A	N A	1.3 7	<0.0050	<0.50
boron		<24.7	N A	NA	NA	<20	<20	<20	NA	NA	NA	<20	<0.20	<20
cadmium		0.578	N A	NA	NA	<0.50	<0.50	<.50	N A	N A	N A	<0.50	<0.0050	<0.50
calcium		2135	N A	NA	NA	<50	<723	<50	NA	N A	N A	5243	4.28	<50
chromium		25.4	N A	NA	NA	<1.0	8.61	<1.46	N A	NA	NA	412	<0.0103	<1.0
cobalt		7.43	N A	NA	NA	<5.0	<5.94	<5.0	NA	N A	N A	14.8	<0.050	<5.0
copper		16.4	N A	NA	NA	<1.0	<6.2	<1.0	NA	N A	N A	26.4	<0.010	<1.0
iron		13567	N A	NA	NA	40.5	3998	78.0	NA	N A	N A	20333	2.68	<5.0
lead		41.0	N A	NA	NA	<5.0	<16.2	<5.0	NA	N A	N A	46.1	<0.050	<5.0
magnesium		1517	N A	NA	NA	<50	<453	<50	NA	N A	N A	2460	1.085	<50
manganese		373	N A	NA	NA	1.55	138.86	3.05	NA	N A	N A	695	0.0933	<0.5
molybdenum		<5.0	NA	NA	NA	<5.0	<5.0	<5.0	NA	N A	N A	4 3. 3	<0.050	<5.0
nickel		13.3	N A	NA	NA	<2.0	<6.86	219	NA	N A	N A	4 3. 3	<0.0384	<2.0
potassium		485	N A	NA	NA	<50	<308	<50	NA	NA	NA	2 8 7	<0.56	<50
sodium		135	N A	NA	NA	<50	<73	<50	NA	N A	N A	1310	3.05	<50
strontium		64.5	N A	NA	NA	<5.0	622.9	<5.0	NA	N A	N A	125	0.0576	<5.0
vanadium		24.3	N A	NA	NA	<5.0	<11.3	<5.0	NA	N A	N A	28.0	<0.050	<5.0
zinc		160	N A	NA	NA	1.82	50.86	234	NA	N A	N A	145	0.192	<1.0
S O W (%)														
solids	(by wt)	52.35	10.54	8.17	8.89	0.12	0.11	<0.11	58.64	57.44	57.68	96.42	N A	N A
indigenous oil		17.48	10.83	0.45	0.30	8.35	0.94	0.33	4.90	2.47	2.16	1.38	N A	N A
water		21.75	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	NA	N A
Solvent (%)														
Isopar-L	(by wt)	<0.1	75.18	62.06	90.23	89.55	100.29	98.02	36.02	42.44	41.33	0.88	0.900	96.07
T P H (µg/g)														
	(wet wt)	146833	N A	NA	NA	999667	998667	1031333	N A	N A	N A	7907	1442	952667
Conventionals standard														
PH	units	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	4.57	N A
alkalinity, total	mg/l	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<2.0	NA
acidity, total	mg/l	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	36.5	N A
BOD5	mg/l	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	76	N A
COD, dichromate	mg/l	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1193	N A
nitrogen, ammonia	mg/l	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.050	N A
nitrogen. Kjeldahl	mg/l	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.535	N A
solids, suspended	mg/l	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	82.3	N A
sulfate	mg/l	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	10.0	N A

ND = not detected

NA = not analyzed

Table 3-2. Carver-Greenfield Process Averages, Test Run 2

Parameters	Units	Waste Feed	Slurried Feedstock			Centrate			Centrifuge Cake-			Final Products		
			A B C			A B C			A B C			Treated Solids	Cond. Water	Cond. Solvent
			A	B	C	A	B	C	A	B	C			
VOC	(µg/kg)													
benzene	(wet wt)	1075.67	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<250	NA
toluene		1046.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<250	NA
ethylbenzene		1886.67	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<250	NA
total xylene (O,m,p)		8873.33	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<250	NA
acetone		<5000	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2 2 8 0	NA
2-butanone (MEK)		<2500	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<395.67	NA
SVOC - acid extractables														
none	(µg/kg)	ND	NA	NA	NA	NA	NA	NA	NA	NA	NA	ND	ND	NA
SVOC - base neutral extractables														
phenanthrene	(µg/kg)	8126.67	NA	NA	NA	NA	NA	NA	NA	NA	NA	c1650	<50	NA
P-methyl naphthalene		49150.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	2316.67	<100	NA
naphthalene	(wet wt)	<28417	NA	NA	NA	NA	NA	NA	NA	NA	NA	1054.67	<50	NA
bis(2-ethylhexyl) phthalate		<50000	NA	NA	NA	NA	NA	NA	NA	NA	NA	1406.67	<196.27	NA
di-n-butylphthalate		(50000)	NA	NA	NA	NA	NA	NA	NA	NA	NA	ND	(20.1)	NA
Metals	(µg/g)													
aluminum	(wet wt)	7351.67	NA	NA	NA	24.77	19.43	19.97	NA	NA	NA	6606.67	13.33	<9.94
barium		575.83	NA	NA	NA	40.53	32.07	32.87	NA	NA	NA	3173.33	<0.50	<0.50
beryllium		0.70	NA	NA	NA	<0.50	<0.50	<0.50	NA	NA	NA	1.12	<0.50	<0.50
boron		<21.93	NA	NA	NA	<20	<20	<20	NA	NA	NA	ND	<20.0	<24.33
cadmium		04.00	NA	NA	NA	<0.50	<0.50	<0.50	NA	NA	NA	5.55	<0.50	<0.50
calcium		7765.00	NA	NA	NA	<50	<50	<50	NA	NA	NA	12633.00	<52.37	<48.27
chromium		139.50	NA	NA	NA	1.54	0.95	<1.07	NA	NA	NA	318.33	<1.0	<1.0
cobalt		9.41	NA	NA	NA	<5.0	<5.0	<5.0	NA	NA	NA	13.23	<5.0	<5.0
copper		8650	NA	NA	NA	<1.35	<1	<1	NA	NA	NA	10733	<1.0	<1.0
iron		20733.00	NA	NA	NA	65.30	33.93	32.67	NA	NA	NA	36433.00	<6.46	<5.0
lead		205.17	NA	NA	NA	<5.0	<5.0	<5.0	NA	NA	NA	248.33	<5.0	<5.0
magnesium		1251.67	NA	NA	NA	<50	<50	<50	NA	NA	NA	1926.67	<50	<50
manganese		276.00	NA	NA	NA	1.12	0.64	0.76	NA	NA	NA	505.33	<0.5	<0.5
molybdenum		2535	NA	NA	NA	<5.0	<5.0	<5.0	NA	NA	NA	4697	<5.0	<5.0
nickel		20.63	NA	NA	NA	<2.0	<2.0	2.0	NA	NA	NA	145.67	<2.0	<2.0
potassium		747.17	NA	NA	NA	<5.0	<50	<50	NA	NA	NA	969.33	<50	<50
sodium		599.17	NA	NA	NA	<50	<52.57	<51.57	NA	NA	NA	2310.00	6797	<53.73
strontium		270.67	NA	NA	NA	<5.0	<5.0	<5.0	NA	NA	NA	378.00	<5.0	<5.0
vanadium		2203	NA	NA	NA	<5.0	<5.0	<5.0	NA	NA	NA	21.27	<5.0	<5.0
zinc		101.33	NA	NA	NA	6.76	2.60	<1.94	NA	NA	NA	1153.33	<1.0	<1.21
SOW	(%)													
solids	(by wt)	52.44	11.26	9.13	9.16	<0.12	<0.1	0.15	68.19	64.35	66.69	98.31	NA	NA
indigenous oil		724	5.89	0.36	0.20	6.61	0.79	0.30	3.64	1.26	1.06	0.85	NA	NA
water		34.77	<0.1	<0.1	0.10	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	NA	NA
Solvent	(%)													
isopar-L	(by wt)	<0.1	78.53	91.34	93.16	8724	100.64	102.30	26.40	31.55	31.23	0.99	0.10	99.70
TPH	(µg/g)													
ignitability	(wet wt) °C	89383	NA	NA	NA	952333	964667	NA	NA	NA	NA	6617	333	923333
		>100	NA	NA	NA	NA	NA	NA	NA	NA	NA	>100	NA	NA
Conventionals	standard units													
PH	units	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.82	NA
alkalinity, total	mg/l	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<3.40	NA
acidity, total	mg/l	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	31.00	NA
BOD ₅	mg/l	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	12.67	NA
COD, dichromate	mg/l	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	394.67	NA
nitrogen, ammonia	mg/l	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.05	NA
nitrogen, kjeldahl	mg/l	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.2	NA
solids, suspended	mg/l	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	70.33	NA
sulfate	mg/l	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	10.0	NA

ND = not detected

NA = not analyzed

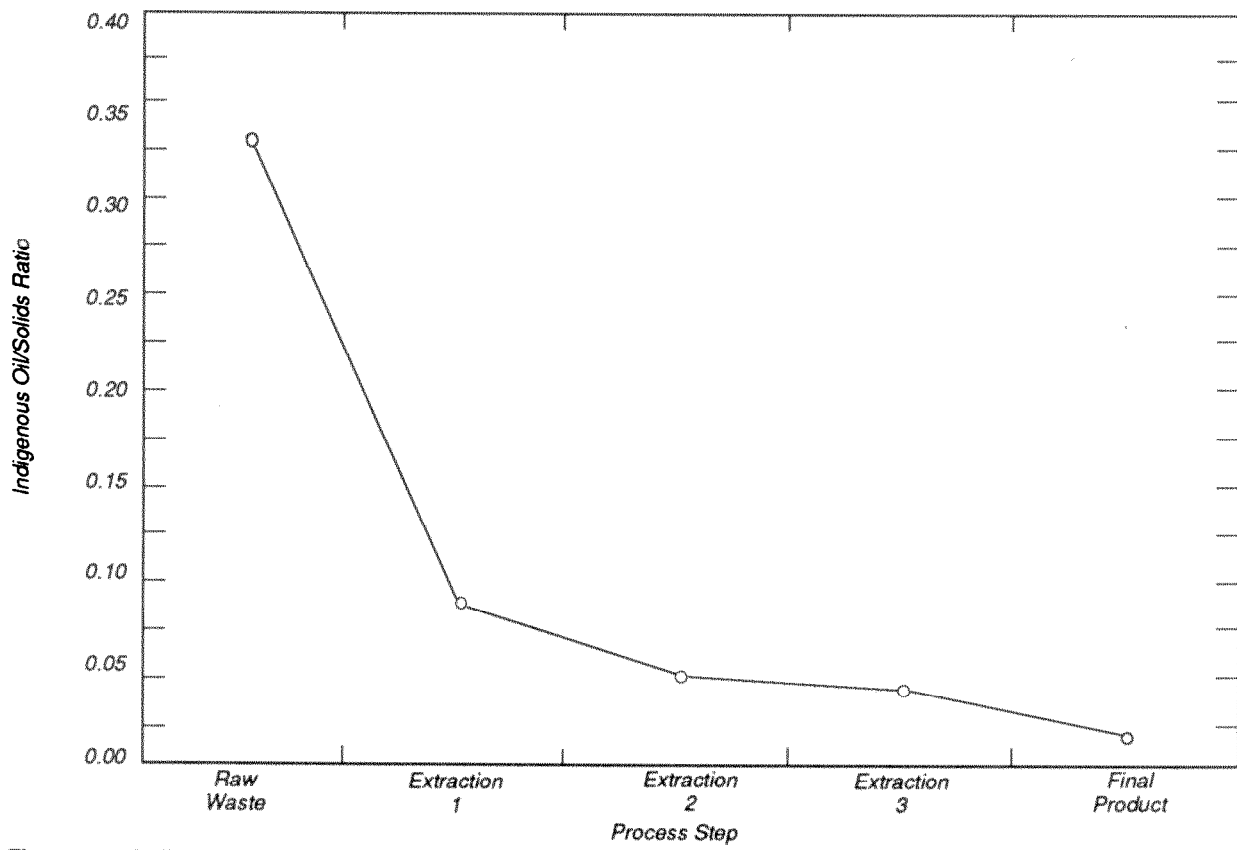


Figure 3-1. Indigenous oil removal for test run 1.

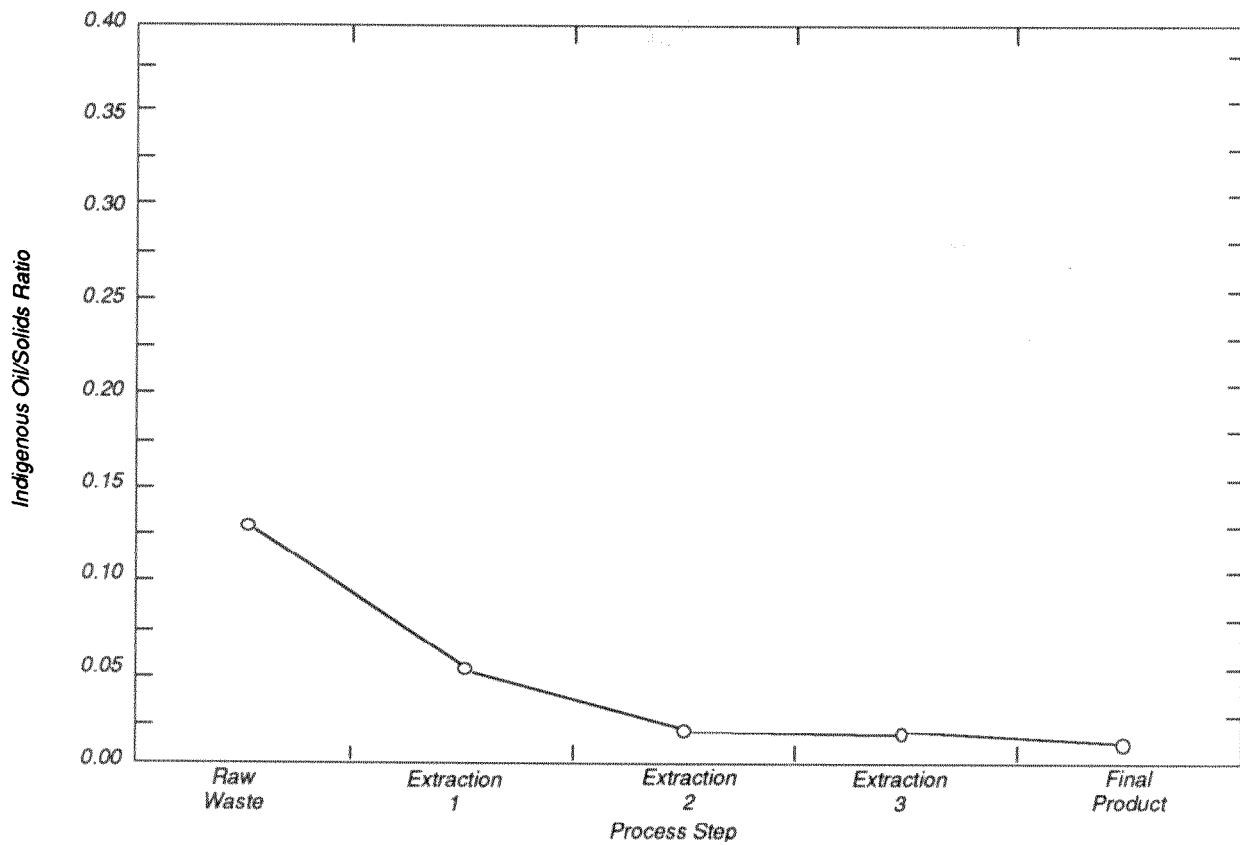


Figure 3-2. Indigenous oil removal for test run 2.

Table 3-3. Oil Removal Efficiency, Expressed as Percentage Removal from Waste Feed

<i>Test Run</i>	<i>Indigenous oil</i>	<i>Indigenous TPH</i>
1	92.1	100
2	88.3	100

Register, 1990). Section 121 (Cleanup Standards) of SARA requires that selected remedies be protective of human health and the environment and be cost-effective. SARA states a preference for remedies that are reliable, provide long-term protection, and employ treatment that permanently and significantly reduces the volume, toxicity, or mobility of hazardous substances, pollutants, or contaminants. The C-G Process is one such remedy. Section 121 also requires that remedies selected at Super-fund sites comply with federal and state applicable or relevant and appropriate requirements (ARAR), and it provides only six conditions under which ARARs for a remedial action may be waived: (1) the action is an interim measure and the ARAR will be met at completion; (2) compliance with the ARAR would pose a greater risk to health and the environment than noncompliance; (3) it is technically impracticable to meet the ARAR; (4) the standard of performance of an ARAR can be met by an equivalent method; (5) a state standard has not been consistently applied elsewhere; and (6) ARAR compliance would not provide a balance between the protection achieved at a particular site and demands on the Superfund for other sites. These waiver options apply only to Superfund actions taken onsite, and justification for the waiver must be clearly demonstrated.

Generally, treatment using the C-G Process will take place onsite, while product water discharge and solids disposal may take place either onsite or offsite. Used solvent that is not recycled is expected to be disposed of at an offsite facility. Onsite and offsite actions must meet the substantive requirements (for example, emission standards) of all ARARs; offsite actions must also meet permitting and any other administrative requirements of environmental regulations.

3.5.2 Resource Conservation and Recovery Act (RCRA)

RCRA regulations define hazardous wastes and regulate their transport, treatment, storage, and disposal. Wastes defined as hazardous under RCRA include characteristic and listed wastes.

Criteria for identifying characteristic hazardous wastes are included in 40 CFR Part 261 Subpart C. Listed wastes from non-specific and specific industrial sources, off-specification products, spill cleanups, and other industrial sources are itemized in 40 CFR Part 261 Subpart D. For RCRA regulations to apply, evidence (for example, manifests, records, and knowledge of processes) must affirm that the waste is hazardous. Site managers may also test the waste or use their knowledge of its properties to determine if the waste is hazardous.

Contaminated media to be treated by the C-G Process will probably be hazardous or sufficiently similar to hazardous waste so that RCRA standards will be requirements. Because the system includes waste storage in tanks, 40 CFR Part 265 standards for tank storage (Subpart J) should be met. Also, RCRA treatment requirements must be met.

Treated solids generated during treatment must be stored and disposed of properly. If the waste feed is a listed waste, treatment residues will be considered listed wastes (unless RCRA delisting requirements are met). If the treatment residues are not listed wastes, they should be tested to determine if they are RCRA characteristic hazardous wastes. In many cases, the solid residues will not be hazardous and can be disposed of at a nonhazardous waste landfill. If the treated solids are found to be hazardous, the following RCRA standards apply.

40 CFR Part 262 details standards for generators of hazardous waste. These requirements include obtaining an EPA identification number, meeting waste accumulation standards, labeling wastes, and keeping appropriate records. Part 262 allows generators to store wastes up to 90 days without a permit and without having interim status as a treatment, storage, and disposal facility. If treatment residues are stored onsite for 90 days or more, 40 CFR Part 265 requirements apply.

Any facility (onsite or offsite) designated for permanent disposal of hazardous wastes must be in compliance with RCRA. Disposal facilities must fulfill permitting, storage, maintenance, and closure requirements contained in 40 CFR Parts 264 through 270. In addition, any authorized state RCRA requirements must be fulfilled. If treatment residues are disposed off-site, 40 CFR Part 263 transportation standards apply.

For both CERCLA actions and RCRA corrective actions, the treatment residuals generated by the C-G Process will be subject to land disposal restrictions (LDR) if they are hazardous and land disposed (U.S. EPA, 1989a). Several LDR compliance alternatives exist for disposing of the treated solids if they are hazardous: (1) comply with the LDR that is in effect; (2) comply with the LDRs by choosing one of the LDR compliance alternatives (for example, treatability variance, no migration petition); or (3) invoke an ARAR waiver (this option would only apply to onsite CERCLA disposal).

40 CFR Part 264, Subparts F (promulgated) and S (proposed) include requirements for corrective action at RCRA-regulated facilities. In addition, these subparts generally apply to remediation at Superfund sites. Subparts F and S include requirements for initiating and conducting RCRA corrective actions, remediating ground water, and ensuring that corrective actions comply with other environmental regulations. Subpart S also details conditions under which particular RCRA requirements may be waived for temporary treatment units operating at corrective action sites.

3.5.3 Clean Water Act (CWA)

The NPDES permitting program established under the CWA issues, monitors, and enforces permits for direct discharges to surface water bodies. Discharges to off-site receiving waters or to publicly owned treatment works (POTW) must comply with applicable federal, state, and local administrative and substantive requirements. Effluent limits are contained in the NPDES permit issued for direct discharges to off-site receiving waters. No NPDES permits are issued for on-site discharges or off-site discharges to POTWs, but all substantive requirements (such as discharge limitations) should be identified and achieved.

3.5.4 Safe Drinking Water Act (SDWA)

The SDWA, as amended in 1986, includes the following programs: (1) drinking water standards; (2) underground injection control program; and (3) sole-source aquifer and wellhead protection programs.

SDWA drinking water primary (health-based) and secondary (aesthetic) maximum contaminant levels will generally be appropriate cleanup standards for water that is, or may be, used as a source of drinking water. In some cases, alternate concentration limits will be appropriate (for example, in cases where multiple contaminants are present). Decision makers should refer to CERCLA and RCRA standards for guidance in establishing alternate concentration limits.

Water discharge through injection wells is regulated under the underground injection program. This program categorizes injection wells as Classes I through V, depending on their construction and use. Reinjection of treated water involves Class IV (reinjection) or Class V (recharge) wells and should meet the appropriate requirements for well construction, operation, and closure.

The sole-source aquifer protection and wellhead protection programs are designed to protect specific drinking water supply sources. If such a source is to be remediated, appropriate program officials should be notified, and any potential problems should be identified before treatment begins.

3.5.5 Clean Air Act (CAA)

Pursuant to the CAA, EPA has set national ambient air quality and pollutant emissions standards. CAA requirements will generally not apply to the C-G Process, although they may apply on a source-specific basis. However, air emissions should be monitored to ensure that they comply with CAA standards.

RCRA air standards generally must be met for CERCLA response actions and RCRA corrective actions. Forthcoming RCRA regulations (40 CFR Part 269) will address air emissions from hazardous waste treatment, storage, and disposal facilities. When promulgated, these requirements will include air emission standards for equipment leaks and process vents, a category that will cover any fugitive air emissions from a C-G Process unit. In addition, states' programs to regulate toxic air pollutants, when established, will be the most significant

regulations for environmental remediation activities. Generally, air emissions from the C-G Process will be minimal, and complying with air emission regulations should not be a problem.

3.5.6 Toxic Substances Control Act (TSCA)

The C-G Process has the capability to handle wastes containing polychlorinated biphenyls (PCB). TSCA requirements set standards for PCB spill cleanups and PCB disposal which should be achieved if PCB waste is treated. The EPA document — CERCLA Compliance with Other Laws Manual, Part II: Clean Air Act and Other Environmental Statutes and State Requirements — discusses TSCA as it pertains to Superfund actions (U.S. EPA, 1989b). The proposed RCRA corrective action regulations (Federal Register, July 1990) state that PCB waste should be handled in accordance with TSCA PCB spill cleanup policy. As TSCA does not regulate direct spills to surface water or drinking water, cleanup standards for these sites are established by EPA regional offices.

3.5.7 Occupational Safety and Health Act (OSHA)

CERCLA response actions and RCRA corrective actions must be performed in accordance with OSHA requirements detailed in 29 CFR Parts 1900 through 1926, especially Part 1910.120, which provides for the health and safety of workers at hazardous waste sites. Onsite construction activities at Superfund or RCRA corrective action sites must be performed in accordance with Part 1926 of OSHA (Safety and Health Regulations for Construction). For example, construction of electric utility hookups for the C-G Process would need to comply with Part 1926, Subpart K (Electrical). Also, any more stringent state requirements would need to be met.

3.6 Impact of Waste Characteristics on Technology Performance

Waste feed characteristics affecting the efficiency of the C-G Process include the following:

1) **Solids Size:** The maximum size of solids that the C-G Process can handle is 1/4 in. If necessary, soils can be pretreated using a grinder to a maximum particle size of less than 1/4 in. Larger particles in the feed may decrease efficiency and cause plugging problems.

2) **Solvent Soluble Content:** The C-G Process can treat wastes with solvent soluble contents from low ppm levels to 75% and higher.

3) **Moisture Content:** Waste streams of up to 99% water can be successfully treated with the C-G Process. Wastes containing high water contents can be pretreated with a dewatering device if suitable.

4) **Selection of Solvent:** Waste characteristics generally govern the choice of carrier solvent. Extraction of indigenous oil and organic materials from solids can be

improved by using additives or specific solvents with a high degree of solvency for target organic components.

3.7 Materials Handling Required by the Technology

For an onsite remediation, materials handling is relatively straightforward. Waste can be excavated and treated concurrently. The C-G Process feed hopper is used to store waste prior to treatment. Carrier solvent can be transported to the site in drums or in bulk, and is easily pumped to the C-G Process unit as needed during processing. The Isopar-L solvent used in the demonstration is a food-grade isoparaffinic oil with a high boiling point (400 °F) and low toxicity, and does not require special handling. Treated solids are transferred directly from the desolventizer to 55-gal drums or to other containers, as required. Residual water can be pumped to an on-site tanker truck for offsite disposal or routed to a POTW. Contaminated carrier solvent is pumped from the distillation unit to 55-gal drums or other vessels for offsite disposal. Materials handling issues specific to the demonstration are described below. During the demonstration, the C-G Process unit was operated in a batch mode using fresh solvent for each extraction, due to the small quantities of waste available. In present full-scale commercial operations, and at an actual site remediation, the C-G Process unit will operate in batch or continuous mode along with solvent distillation and recycle, thereby significantly reducing the need to handle individual drums of carrier solvent.

EPA performed all materials handling at the Edison facility during the demonstration. The waste was pretreated to the maximum particle size of 1/4 in. during excavation. Isopar-L solvent was stored in 55-gal drums onsite. About 1,600 lb of solvent were charged to the fluidization tank using a fork lift. The intent was to have a solvent to feedstock solids ratio of 10: 1. At a full-scale remediation, Isopar-L would be pumped to the C-G Process unit from bulk tanks, thus minimizing solvent handling requirements. Steam was supplied by an onsite boiler adjacent to the C-G Process unit.

The final solids product and recovered water was virtually free of toxics and did not require special handling. Product

water was collected in 55-gal drums. Solvent product containing organic constituents and solvent required special handling. It was collected in 55-gal drums for disposal as a hazardous waste and stored in a containment area. The required signs were posted throughout the containment area.

3.8 Community Impact

The demonstration's impact on the community surrounding the EPA facility was minimal. Potential hazards to the community at a Superfund remediation include the following:

- * Air emissions
- * Dust releases
- * Transportation hazards

Air emissions from the C-G Process are extremely low due to the closed configuration of the evaporator. Dust releases from both pretreatment and processing can be minimized with dust control equipment. At a full-scale remediation, the most significant local impact would be the erection of the evaporation tower, a structure several stories tall, and hazards of removing the contaminated carrier solvent from the site.

3.9 Personnel Issues

During the demonstration, the C-G Process unit operated 10 hr/day. Two operators were needed to run the C-G Process pilot-scale unit; however, larger scale C-G Process units may require additional operators. At the EPA facility, steel-toe shoes and safety glasses were required. In addition, respirators were provided for use in emergencies. Emergency eye-wash stations, first aid kits, and fire extinguishers were located throughout the facility.

The C-G Process contains many safety features in its design. The unit can be shut down quickly if problems occur or if the range of predetermined operating conditions is exceeded. Nitrogen removes residual oil from solid particles, preventing explosive atmospheres from forming. Also, the solvent has an extremely low volatility, and thus does not readily generate explosive or hazardous atmospheres.

Section 4

Economic Analysis

An important goal of the SITE Program is to develop reliable cost data for innovative and commercially available hazardous waste treatment. The purpose of this economic analysis is to estimate costs for a full-scale remediation using the Carver-Greenfield (C-G) Process at a Superfund site. The C-G Process unit used during the SITE demonstration was a pilot-scale plant, capable of treating about 100 lb of waste per hour (DTC, 1989). During the actual demonstration, the C-G Process unit treated about 640 lb of drilling mud wastes in two test runs.

Due to its relatively low throughput, the pilot-scale C-G Process unit is not cost-effective for a full-scale Superfund site remediation. Therefore, costs are based on a mobile C-G Process unit designed to treat 1.4 tons/hr at a site similar in size and waste characteristics as the PAB Oil Superfund site. The cost analysis presented in this section is based on treating a total of 23,000 tons of waste.

Capital cost data for the C-G Process were obtained primarily from DTC. Other sources of cost information included EPA experience in CERCLA remediations and the SITE demonstration. The costs associated with the C-G Process have been placed into 12 cost categories applicable to typical cleanup activities at Superfund and RCRA sites. These cost categories are discussed in this section as they apply to the C-G Process. Table 4-1 presents estimated costs per ton for waste treated at a typical Superfund site with waste material similar to the drilling mud treated in the demonstration. Treatment costs are based on treatment at the waste location. Costs presented in this analysis are order-of-magnitude estimates (-30% to +50%).

4.1 Site-Specific Factors Affecting Cost

A number of site-specific factors affect the cost of the C-G Process. These factors can vary greatly depending on the site being remediated. Factors affecting costs generally include 1) the volume of waste to be treated; 2) waste characteristics such as water content, particle size distribution, and type and concentration of contaminants in the waste; 3) treatment goals; and 4) residual disposal costs.

4.2 Basis of Economic Analysis

The C-G Process can be applied to several types of waste, including wastewater sludges, contaminated soils, and petroleum refinery wastes, such as dissolved air flotation (DAF)

sludge. This economic analysis is based on petroleum-based drilling mud waste as the feed. Costs are presented in terms of dollars per wet ton of feed. Not all the cost categories for treating this particular material may apply to other types of waste. Therefore, only applicable categories should be used when estimating the costs for a given site.

In this economic analysis, the C-G Process unit is assumed to operate 24 hr/day, 7 days/wk, and 52 wk/yr. A 24-hr operation with an on-line factor of 70% is used. It is not economical to shut down the C-G Process unit daily because the energy and time required to heat the evaporator and other heat exchange surfaces to operating temperatures entail high costs if the system is shut down and restarted each day. The 70% factor accounts for time required to respond to operational problems, as well as maintenance operations. Estimates for on-line factors of 50% and 60% are discussed in Section 4.3.

For this analysis, certain assumptions, derived from the demonstration, were made regarding the waste feed and the operating conditions.

Assumptions Regarding Untreated Waste Feed

- The waste is a petroleum-based drilling mud similar to the material used in the demonstration, with the following composition by weight 52% solids, 17% indigenous oil; and 31% water.
- Waste is excavated and treated concurrently at the site.
- The raw waste must be screened to a maximum particle size of 1/4 in: Although drilling mud solids consist of very small particles, some clumps of solids requiring screening were observed during the demonstration.

Assumptions Regarding Operating Conditions

- Technicians will collect all samples and perform equipment maintenance and minor repairs.
- The system operates at a waste feed rate of 1.2 yd³/hr (1.4 tons/hr).
- * Operating the system requires five workers: one supervisor, one feed operator, two system operators, and one maintenance operator.

Table 4-1. Estimated Costs Associated With the C-G Process Technology

	(\$ per ton of waste)
Site Preparation Costs	
Site design and layout	-
Survey and site investigations	-
Legal searches	-
Access rights and roads	-
Preparations for support facilities	-
Utility connections	-
Auxiliary buildings	-
Technology-specific requirements (excavation)	55.00
Total Site Preparation Costs	55.00
Permitting and Regulatory Costs	
Permits	-
System monitoring requirements	-
Development of monitoring and protocols	-
Total Permitting and Regulatory Costs	-
Capital Equipment Costs	
Major equipment	21.85
Support equipment	-
Equipment rental	-
Total Equipment Costs	21.85
Onsite Startup and Fixed Costs	
Mobilization :transportation to and from site assembly	0.37
Shakedown and testing	0.74
Contingency	1.16
Total Startup and Fixed Costs	2.20
Labor Costs	
Feed operators	25.51
Maintenance mechanic	30.61
Sys tem operator	81.64
Engineering/Supervisor	25.51
Total Labor Costs	163.27
Supplies Costs	
Isopar-L @\$1.50/gal	8.90
Total Supplies Costs	8.90
Consumables Costs	
Cooling water	0.44
Fuel (steam)	7.35
Nitrogen	5.84
Electricity	1.73
Total Consumables Costs	15.36
Effluent Treatment and Disposal Costs	
Non-contact cooling water	-
Total Effluent Treatment and Disposal Costs	-
Residuals & Waste Shipping, Handling, & Transport Costs	
Waste disposal (incineration @ \$200/drum)	239.64
Onsite facility costs (backfill solids on site)	7.23
Offsite facility costs (wastewater disposal at POTW)	0.15
Total Residuals & Waste Shipping, & Transport Costs	247.02
Analytical Costs	
Operations	-
Environmental monitoring	-
Total Analytical Costs	-
Equipment Repair & Replacement Costs	
Design adjustments	-
Facility modifications	-

Scheduled maintenance	4.79
Equipment replacement	-
Total Equipment Repair & Replacement Costs	4.79
Site Demobilization Costs	
Disassembly	2.78
Site cleanup and restoration	-
Permanent storage	-
Total Site Demobilization Costs	2.78
Total Operating Costs (\$/TON)	523.44

4.2.1 Site Preparation Costs

Site preparation costs include access rights, site layout, legal searches, roads, utility connections, and excavation and pretreatment of waste. This cost analysis assumes that preliminary site preparation will be performed by the responsible party. Site preparation costs will vary depending on the type, condition, and geographical location of the site. Sites where excavation is difficult will have significantly increased site preparation costs. Also, waste requiring extensive pretreatment will increase costs in this category.

Estimates for site preparation are based on an excavation rate of about 1.2 yd³/hr. Minimum requirements are one backhoe, available for \$4,000/mo, one supervisor at \$40/hr, and one excavator operator at \$30/hr, yielding an excavation cost of about \$55/ton (Means, 1991). For the purposes of this cost analysis, it is assumed that excavation will occur concurrently with waste treatment. Pretreatment costs involve operation of screening equipment and are included in equipment operating costs of the C-G Process equipment, Section 4.2.5.

4.2.2 Permitting and Regulatory Costs

Permitting and regulatory costs depend on whether treatment is performed on a Superfund or a RCRA corrective action site and on the fate of the treated waste. Section 121(d) of CERCLA, as amended by SARA, requires that remedial actions be consistent with ARARs of environmental laws, ordinances, regulations, and statutes. ARARs include federal standards, as well as more stringent state or local standards. ARARs must be determined on a site-specific basis. Because permitting costs can vary greatly depending on the site, they are not included in this analysis.

4.2.3 Capital Equipment Costs

Capital equipment costs include the cost of the trailer-mounted C-G Process unit and the auxiliary equipment, which includes a distillation column and screening equipment. Total equipment costs are estimated at \$1.3 million. The capital costs shown in Table 4-1 are based on information provided by Dehydro-Tech and assume financing at 7%/yr over 10 yr.

4.2.4 Startup and Fixed Costs

Startup and fixed costs include mobilization, crane rental, and labor expenses for assembly and shakedown of the system. Mobilization includes both transportation and assembly.

Transportation costs are based on transporting three trailers. A 1000-mile basis is assumed, with a \$4,000 permit fee for one oversize trailer, with an overall transportation cost of \$1.50/mile. The C-G Process requires a 5-ton crane to lift the vertical evaporator into place. Crane rental costs include an operator and are estimated at \$2,000/wk for two wk. Shake-down operations involve testing each major unit operation (evaporation, centrifugation, and deoiling), and establishing operating parameters for the waste stream; these costs would primarily consist of labor charges, and are estimated at \$12,800.

Onsite startup costs are based on one month of labor costs for four persons at \$40/hr, plus travel and living expenses, and total about \$100,000, including contingency. Contingency costs include unforeseen events, such as additional time to optimize the process operation for a particular waste stream, and are estimated at \$50,000. Actual startup costs would vary with site conditions and include factors such as available land and utility connections.

4.2.5 Labor Costs

Labor costs are based on the following: one feed operator at \$25/hr (three shifts/day), two system operators at \$40/hr (three shifts/day), one maintenance mechanic at \$30/hr (three shifts/day), and one engineer/supervisor at \$75/hr (one shift/day). The feed operator operates screening equipment and the feed hopper. Rates include overhead and administrative costs. Existing C-G Process units use local personnel for all system operations. It is therefore assumed that after startup and shakedown is complete, local workers will operate the unit.

4.2.6 Supplies Costs

Supplies consist of Isopar-L, the carrier solvent. Based on data from ongoing operations and from the demonstration, about 6 gal/ton of feed (8.3 gal/hr) of Isopar-L will require replacement due to losses in the bottoms of the distillation operation. This results in a total cost of about \$202,000, or \$8.90/ton. However, this cost depends on the oil content of the waste, the physical properties of the organic contaminants and the efficiency of the distillation operation.

4.2.7 Consumables Costs

Consumables costs include costs for cooling water, steam, nitrogen, and electricity. The quantities used depend on the waste feed rate, the water content of the waste, and the scale of operation. In this analysis, bulk pricing for steam is estimated at \$5 per million British Thermal Units (Btu). Based on operating data from existing operating units, the C-G Process plant is estimated to use about 1.47 million Btu per ton of waste, resulting in a unit cost for steam of \$7.35/ton.

The cooling water systems used by full-scale C-G Process plants are closed-loop, limiting water costs to the operating costs of an onsite cooling tower. These costs are based on using a 205-gal/min tower, and are estimated at \$0.05/1,000 gal, or \$0.44/ton.

The C-G Process uses nitrogen in deoiling operations. Nitrogen consumption depends on the levels of residual oil

required in the final solids product, and may depend on local requirements at a particular site. Nitrogen use is estimated at about 1,620 standard ft³/hr (SCFH). A nitrogen cost of \$5/thousand ft³ results in a unit cost of \$5.84/ton

The C-G Process unit requires 480-volt, three-phase electric power. The electric power requirements are primarily for motors, pumps, and the centrifuge in the system. With a usage rate of about 40 kilowatts and a cost of electricity of \$0.06 per kilowatt-hour, unit cost for electric power is \$1.73/ton.

4.2.8 Effluent Treatment and Disposal Costs

The full-scale C-G Process unit uses a completely closed system to circulate non-contact cooling water. As stated earlier, the cooling water used in a full-scale remediation would be pumped through an onsite cooling tower and would require very little makeup. Therefore, disposal costs for this stream are insignificant and are not included in this cost analysis.

4.2.9 Residuals Shipping, Handling, and Transportation Costs

During the demonstration, the C-G Process unit produced three residual streams: a dry solids product, a water stream, and an oil phase, consisting of a mixture of the Isopar-L and indigenous organic wastes.

The dry solids product passed TCLP criteria and exhibited very low levels of petroleum hydrocarbons. Therefore, disposal costs are based on backfilling this material at the site, at a cost of \$15/ton. If, however, solid residues must be disposed of at an off-site landfill, costs will increase to about \$45/ton. This cost reflects transportation, disposal, and other customary charges for offsite disposal in a sanitary landfill within 100 miles of the waste site.

Disposal costs of residual water from waste treatment are based on disposal of about 1.6 million gal of water to a local POTW. Total water disposal costs are estimated at \$2/1000 gal, resulting in a unit cost of \$0.15/ton of waste.

Residual oil disposal includes the original volume of Isopar-L carrier solvent, all makeup solvent, and all indigenous oils from the waste. The total volume of oily waste is estimated at 1.52 million gal. Disposal costs are based on a unit cost for transportation and incineration of \$200/55-gal drum, resulting in a unit cost of about \$240/ton of waste treated.

4.2.10 Analytical Costs

Analytical costs include those for laboratory analysis, data reduction and tabulation, QA/QC, and reporting. These costs are for verification of treatment effectiveness and do not include waste characterization. Analytical costs will vary according to the types of contaminants and regulatory requirements for the waste and therefore are not included in this cost analysis.

4.2.11 Equipment Repair and Replacement costs

During operation, some parts of the unit may require repair or replacement. For this analysis, annual equipment repair and replacement costs are assumed to be about 3% of capital costs, or \$4.79/ton.

4.2.12 Site Demobilization Costs

Site demobilization normally includes items such as operation shutdown and decommissioning of equipment and disconnection of utilities. This analysis bases demobilization costs only on disassembly of process equipment, and are estimated at \$2.78/ton. Transportation costs are included in the mobilization category. Disassembly consists of lowering the vertical falling-film evaporator with a crane. Crane rental costs are estimated at \$2,000/wk for two wk.

4.3 Summary of Economic Analysis

Considering the 12 cost categories and the assumptions made in this economic analysis, the estimated cost per ton for treating drilling mud wastes at 1.4 tons/hr is \$523/ton. This cost includes pretreatment, startup, capital, operating, and residual disposal costs for a C-G Process mobile unit treating waste at a Superfund site similar to the PAR Oil site with an on-line factor of 70%. Of the \$523 per wet ton cost, \$221 is C-G Process-specific and \$302 is site-specific. Of the \$302 per ton site-specific cost, about \$240 is for the incineration of indigenous oil separated from the feed. Variations in the on-line factor increases technology-specific costs only. An on-line factor of 60% results in a unit cost of \$560/ton, while a 50% on-line factor increases the cost to \$611/ton.

As mentioned earlier, costs presented in this analysis are order-of-magnitude estimates (-30% to +50%) and are rounded

to the nearest dollar. Also, factors that affect the estimated cost of the C-G Process unit are highly site-specific. Variability in site and waste characteristics and in residual transportation and disposal costs could significantly affect the costs presented in this economic analysis.

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Appendix A

Carver-Greenfield Process Description

A.1 Background

The primary purpose of the C-G Process is to separate multi-phase mixtures into their respective solids, indigenous oil, and water fractions. The process is based on suspending solids containing water and oils in a "carrier" oil or solvent. This solvent keeps the viscosity of the mixture low, permits high heat transfer rates, and prevents scaling or fouling of heat transfer surfaces as the water in the mixture evaporates. The resultant product solids are virtually water-free (<5% by weight). Organics indigenous to the materials processed are extracted by the carrier solvent. In the demonstration, these consisted of petroleum-based hydrocarbons and other oil-soluble organics. Thus, the separation process produces dry solids, from which the indigenous oils and organics have been extracted.

A.2 The Carver-Greenfield Process System

The C-G Process involves slurring the feed material with a carrier solvent; evaporating water from the slurry in a high-efficiency multi-effect evaporator; separating the solvent from the feed solids in a centrifuge; and evaporating the solvent from the solids. The used carrier solvent is distilled to separate the indigenous oils and organics and to recover reusable solvent. Residuals (products) from the process include (1) a concentrated mixture of the extracted indigenous oil and organics, (2) water substantially free of solids and oils, and (3) clean, dry solids. The following sections briefly describe the major unit operations in the C-G Process, as shown in the general schematic flowsheet for commercial systems (Figure A-1). First, the process is described as it would be applied on a commercial scale. The final section discusses application on a pilot scale.

A.2.1 Slurrying

The first step involves slurring the feedstock with a solvent. The particular solvent used depends on the application and the disposal method for the extracted materials. Generally, a hydrocarbon-based solvent with a narrow boiling range around 400 °F is used for hydrocarbon or organically contaminated solids. Five to ten lb of solvent/lb of waste solids is typically needed for slurrying. Any dense debris in the feed is first separated; if necessary, the feed solids are ground to particle sizes of less than 1/4-in. The feed characteristics and the process objective generally determine the solvent-to-waste solids ratio. Higher ratios promote fluidization for easy transfer of the slurry and increase efficiencies for extracting soluble organics into the solvent.

A.2.2 Evaporation/Heat Exchange

The solvent/feed slurry is circulated through an energy efficient single or multi-effect evaporator system to remove the water. The solvent is thoroughly mixed with the solids to achieve extraction of indigenous oils (including petroleum based oils) and solvent soluble organic compounds. The multi-effect evaporation is counter-current to the fluid slurry and the steam. For example, in the two-effect evaporator shown in Figure A-1, steam from a boiler heats the recirculating slurry in the second effect (at about 250 °F, under slight vacuum). Steam from the recirculating stream leaves the second effect at a lower temperature (212 °F) and heats the recirculating slurry in the first effect, which operates under higher vacuum, thereby reducing the boiling point of water. Because of the lower boiling points, heat from the steam can be reused. Thus significantly greater amounts of water can be evaporated per unit of boiler steam, in a multi-effect system. Process design and operation typically removes equal amounts of water in each effect. The number of effects in the evaporator system depends on the slurry characteristics and water content. Generally, commercial systems have two to four effects.

The evaporation step can enhance organics extraction efficiency by breaking up emulsions holding the compounds in the solids. In addition, volatile compounds in the feed are stripped in this step and are condensed with the vaporized water and small quantities of solvent. Any pathogens or microorganisms in the feed are also destroyed by the heat, yielding a sterile final product.

A.2.3 Centrifuging

The slurry is sent to a centrifuge from the evaporation section to separate most of the solvent from the solids. The solids are then either reslurried with clean (recirculated) solvent for additional extractions or treated to remove residual solvent. The centrifuge cake is typically about 50% solvent or greater (with extracted organics) and 50% solids. The centrate will essentially be the solvent with extracted indigenous oil and organics and less than 1% solids (fines). The solvent may be recycled after separating the solvent from the indigenous organics by distillation.

A.2.4 Desolventization

After final centrifuging, residual solvent is removed from the solids by desolventization. This process relies on evaporation and gas stripping to separate the solvent from the solids. The heated stripping gas (such as nitrogen or steam) is scrubbed

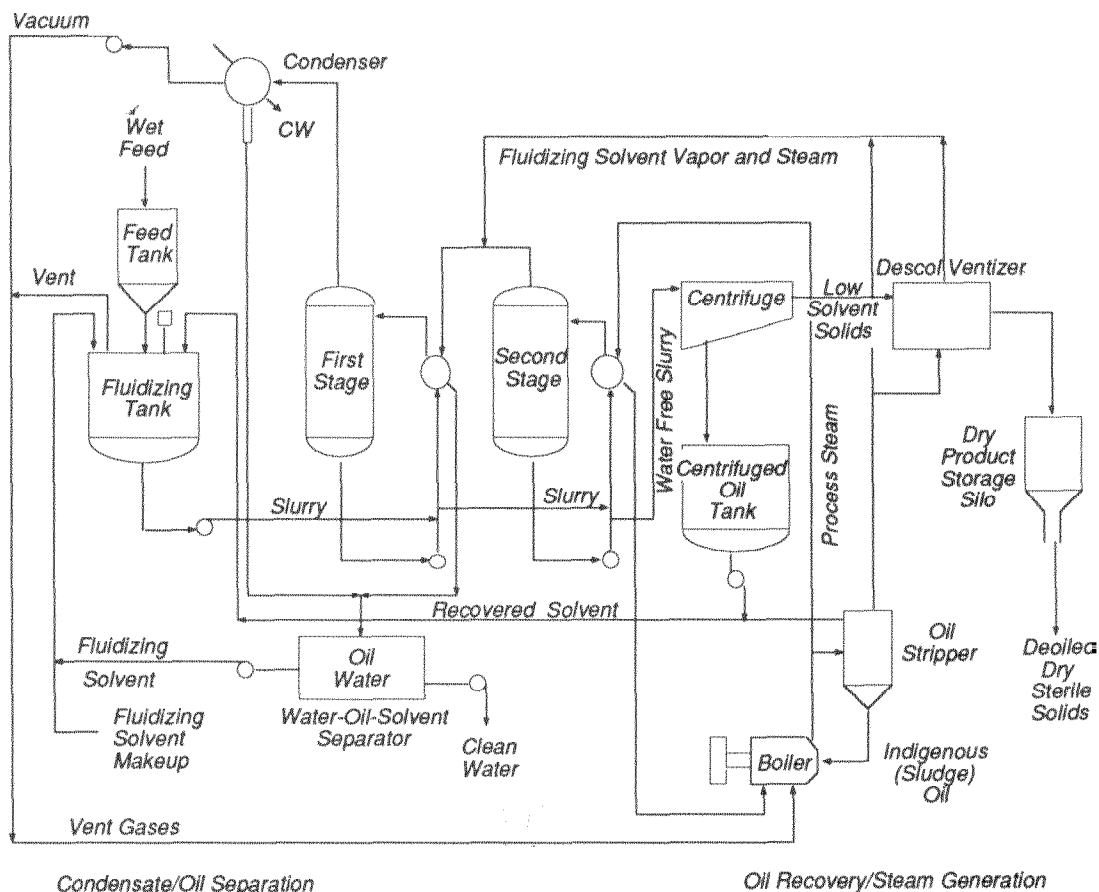


Figure A-1. General process schematic for commercial C-G systems.

(of solvent vapor) and recirculated to the desolventizer. The final dry solids product is clean and typically contains less than 3% water. The residual oil and indigenous organics levels in the solids depends on extraction efficiency, the number of extractions, and the initial levels in the feed. The desolventizer will not evaporate most of the heavy indigenous oils remaining in the centrifuge cake; these remain with the solids fraction.

A.2.5 Distillation

Fractional distillation separates extracted impurities from the solvent, producing a recovered solvent substantially free from impurities and a concentrated stream of extracted "light" and "heavy" organics (relative to the boiling point of the solvent). The recovered solvent is reused in the slurrying process. The concentrated streams of extracted indigenous oils and organics can either be incinerated (for example, in the boiler as shown in Figure A-1) or reclaimed.

A.2.6 Oil/ Water Separator

The water removed from the slurry in the evaporation step is collected in a decanter after condensation. Water-immiscible solvent condensed with the evaporated water is removed, leaving relatively clean water, virtually free of

solids, with a low residual solvent content. It may contain low-boiling water-soluble compounds extracted from the feed waste and can typically be treated with standard wastewater treatment technologies, either onsite or at an offsite treatment plant. Treatment options will depend on the characteristics of the feed waste.

A.2.7 Vent Gases

All unit operations are closed, and the vent gases are collected in a single stream. The major sources of vent gas are the evaporation section and the desolventizer, but losses are small due to high efficiency condensers. The vents are treated for residual organics reduction by passing the gas through granular activated carbon canisters.

A.2.8 Pilot Scale Applications

Commercial-scale systems normally operate continuously. The mobile pilot unit used in the SITE demonstration differed in several aspects from the commercial system:

- * A single-effect evaporation step was used for drying, and extraction was done on a batch basis.

- The distillation step for separation and recovery of the solvent was not performed because DTC did not have pilot-scale distillation equipment at the time of the demonstration. Commercial systems have a separate, dedicated multi-stage distillation operation. Fresh solvent was used for each evaporation and extraction.
- Nitrogen was used as the stripping gas for the desolventizer operation, and would be recommended for most commercial operations.

The C-G Process was first commercialized in 1961. Since then it has been licensed in over 80 plants around the world to dry municipal and industrial sludges and other biomass wastes. Three commercial municipal sludge plants are operating in Japan, treating municipal and industrial primary and waste activated sludges and night soil with solids contents of 4.5% and higher. In the United States, the City of Los Angeles operates one C-G Process plant. Two other similar municipal sludge facilities are under construction. Another municipal sludge facility in Ocean County, NJ is producing fertilizer.

In recent years Dehydro-Tech Corporation (DTC), the sole licensor of the C-G Process, has conducted a number of pilot plant studies to establish whether the C-G Process is suitable for processing petroleum sludges and other industrial wastes at appropriate Superfund sites. Results of this work is summarized in Appendix D.

In 1984, waste samples from an oil refinery were treated in the C-G Process pilot plant in East Hanover, NJ. The waste samples were from DAF sludge, API separator bottoms, tank bottoms, bio-sludge, and primary/secondary emulsions. The waste samples were mixed in different proportions to produce three feed mixtures. Starting with feed materials having a high indigenous oil-to-solid ratio (in the range of 25 to 40), the C-G Process produced solids containing only 3.8% to 5.4% indigenous oil. The hazardous compounds originally present in the feed materials, such as benzene and phenol, were also removed from the solids.

In 1985, DTC used the C-G Process to treat slop oil samples from an oil company's wastewater pond. The slop oil sample was successfully separated into its solid, water and oil-soluble (indigenous oil) products at the pilot plant in East Hanover, NJ. The original slop oil was unsuitable for landfilling due to hazardous compounds, such as benzene, toluene and chromium. Test results for final solid products revealed that the final dry product met all the requirements for non-hazardous landfilling, as specified by EPA.

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Appendix B

Vendor's Claims for Carver-Greenfield Process Technology

B.1 Introduction

The patented Carver-Greenfield (C-G) Process represents an important new approach to remediating soils, petroleum K-wastes, spent drilling muds, and other hazardous sludges containing petroleum-based contaminants, such as fuel oils, PCBs, and polynuclear aromatics (PNAs). The process is well-proven and has been used extensively over the past 30 yr to dry and extract compounds from a variety of wet, oily solids. The C-G Process™ can efficiently separate oily soils and sludges into three products for final disposition: (1) indigenous oil compounds, (2) evaporated water, and (3) dry, decontaminated soil.

Dehydro-Tech Corporation (DTC) has licensed over 80 C-G Process facilities worldwide over the past 30 yr to solve waste disposal problems in a variety of fields. 53 of these licensed facilities are designed to dry and deoil slaughterhouse wastes (from rendering plants). The other plants are designed to evaporate water and extract indigenous oil from a broad spectrum of materials, including municipal and industrial sewage sludges, wool scouring wastes, petrochemical sludges, wood pulp wastes, pharmaceutical wastes, dairy and food products, textile and dye wastes, animal manure, etc. Growing environmental concerns have accelerated the demand for the technology in recent years, as indicated by the increase in cumulative licensed capacity shown in Figure B-1.

Many of the current applications of the C-G Process have processing requirements very similar to oily soil and sludge treatment. For example, dewatered municipal sewage sludge typically contains over 20% solids and has a high ash ("sand") content. Commercial C-G Process plants extract and recover the indigenous sewage oil (which represents about 10 weight percent of the total solids) and dry the solids to less than 5% moisture.

B.2 Process Description

A simplified process flow diagram of a commercial design including 3 extraction stages is shown in Figure B-2. As a first step, the pre-screened oily soil and sludge are fed to a water evaporation section, where they are mixed with a water-immiscible solvent to form a slurry. Different types of solvents are used, depending upon the feed properties and desired product characteristics. For soil remediation applications, alcohols or food-grade mineral oils having a boiling point of about 400 °F are typically used.

In the evaporation section, the water in the feed is evaporated from the slurry and the first stage of extraction takes place. In addition to extracting contaminants from the solids, the solvent fluidizes the solids and ensures a low slurry viscosity as the solids become dry. The solvent also prevents scaling and fouling of the heating surfaces, thereby ensuring good heat transfer. By evaporating the water, problems with emulsions are avoided, even with "difficult-to-process" feeds.

The vapors leaving the evaporation section are condensed and any water-immiscible solvent present is easily decanted from the water. The solvent containing extracted oil leaves the first stage of extraction and is separated from the extracted oily contaminants in a distillation column. The concentrated recovered oil is removed for disposal. The clean, distilled solvent is recycled to the third stage of extraction.

The solids leaving the evaporation section are fed to two additional stages of countercurrent extraction to achieve a higher degree of decontamination. The residual solvent left on the solids after the third extraction is recovered by heating and purging the solids with steam or nitrogen ("desolventizing").

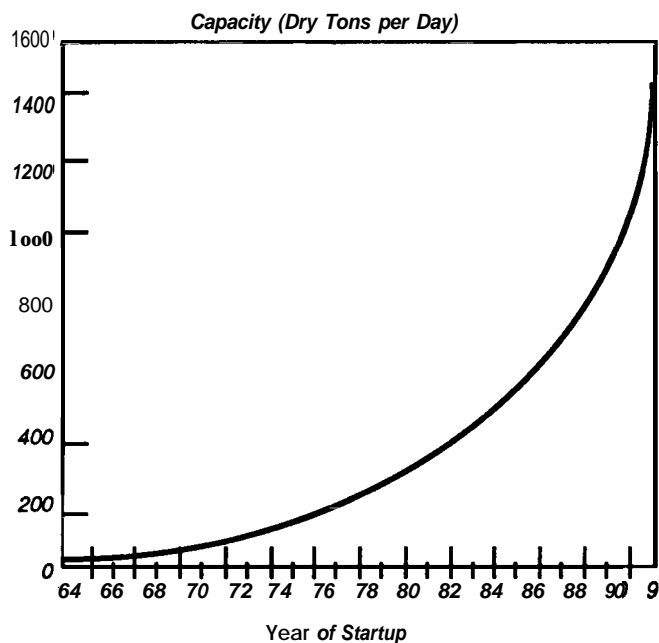


Figure B-1. C-G process licensed capacity.

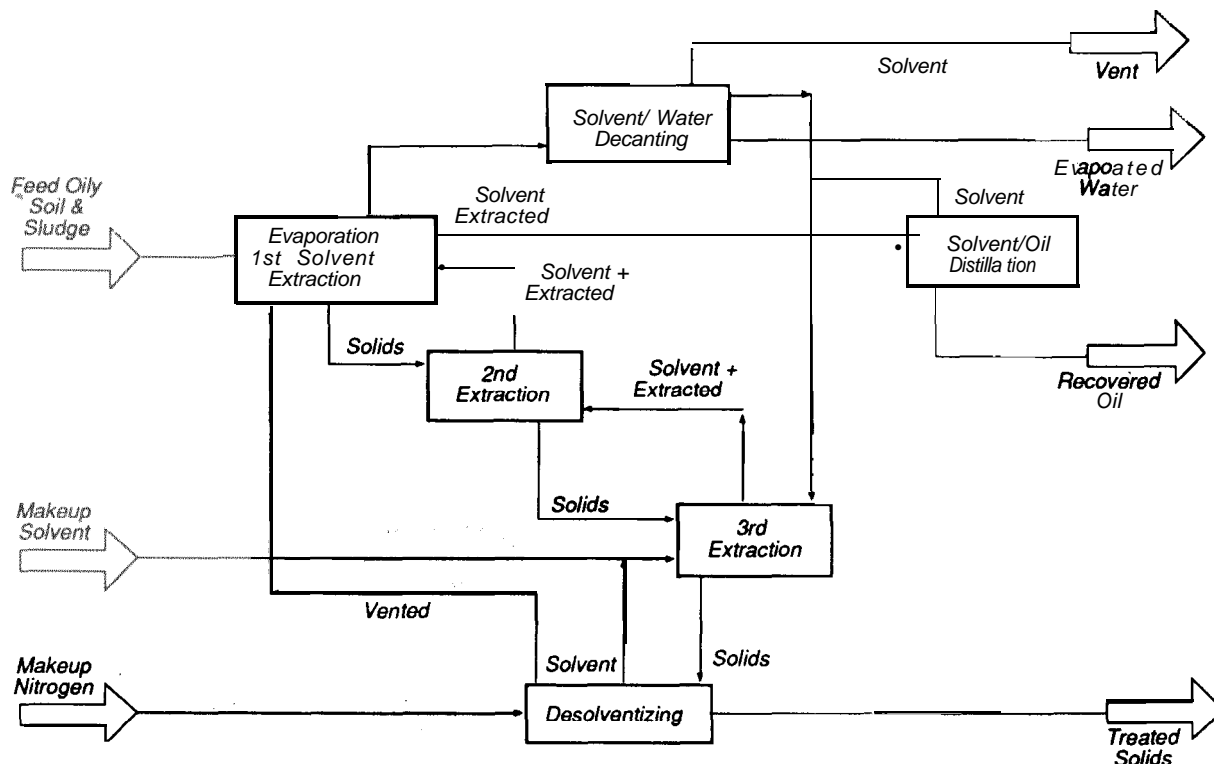


Figure B-2. C-G process block & flow diagram.

Each of the three products generated when treating oily soils and sludges with the C-G Process are in a form that is convenient for final disposition. In many cases, the solids are decontaminated and can be landfilled. If the treated solids still contain unacceptable levels of inorganic compounds, such as heavy metals, this reduced volume of waste can be chemically "fixed" to make the metals non-leachable. Removal of the petroleum contaminants greatly improves the effectiveness of chemical fixation techniques. The extracted oil-soluble compounds can be refined and reused or, alternatively, burned to destroy the hazardous compounds and/or to produce steam. The evaporated water recovered from the feed can usually be sent directly to a wastewater treatment plant.

Particle Size of Processed PAB Oil Site Solids

The particle size analysis of the product solids from the C-G Process demonstration on the PAB Oil Site material reveals that the process can treat solids having smaller particle sizes than have been typically capable of being handled by conventional soil washing techniques. Table B-1 summarizes the particle sizes analyzed by laser light scattering (MICROTRAC).

The data from Table B-1 has also been plotted on Figure B-3 as superimposed curves on Figure 1. Soil Washing Applicable Particle Size Range (EPA/540/2-90/017, 9/90, Engineering Bulletin: Soil Washing Treatment). The plot of the ultimate particle sizes fall within the "Difficult Soil Washing Regime (III)" while the agglomerated particles are barely within the "Soil Wash with Specific Washing Fluid Regime

(II)". This shows that the C-G Process has been demonstrated to be capable of processing materials which have been shown heretofore to be difficult or impossible to process using presently developed soil washing techniques.

Table B-1. Particle Size Analyses-Product Solids-PAB Oil Site

Particle Size, microns	Ultimate Particles, % Passing	Agglomerated Particles, % Passing
704	—	100.0
498	—	89.0
352	—	78.5
249	100.0	70.2
176	99.8	63.7
125	98.8	58.1
	97.3	53.3
62	94.7	46.8
44	89.2	40.8
31	79.9	34.9
22	68.4	27.9
15	57.0	21.5
11	48.0	16.6
8	40.8	12.9
6	36.6	9.8
4	20.7	6.6
3	9.3	4.3
2	1.3	2.1
1	0.0	0.8
Average Size	12.0 Microns	73.4 Microns

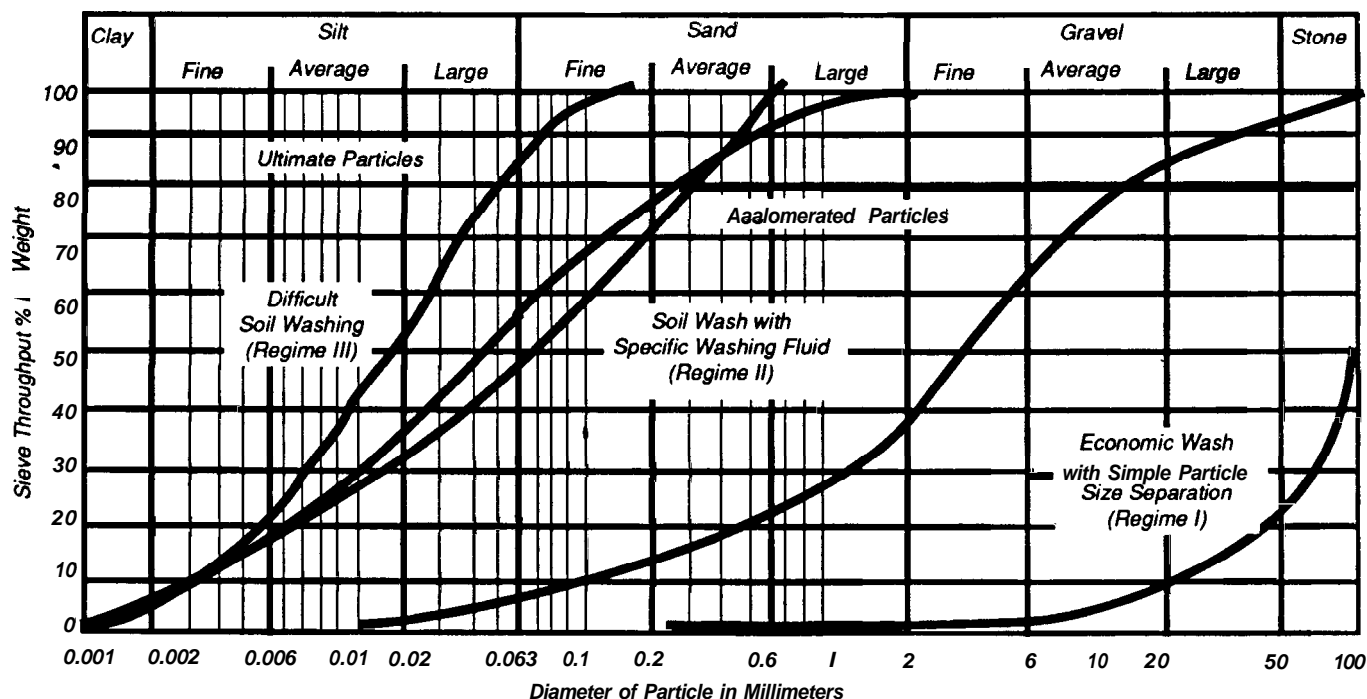


Figure B-3. Particle size distributions of C-G processed solids from PAB Oil Site.

B.3 Process Economics

Table B-2 shows the estimated economics for a commercial C-G Process plant designed to remediate the PAB Oil site in about 2.7 years. The plant can treat 2,771 lb/hr of spent contaminated soil and spent drilling muds with the following composition:

Component	Weight Percent
Water	31.0
Indigenous Oil	17.0
Solids	<u>52.0</u>
Total	100.0

An overall material balance is given at the bottom of Table B-2. With an assumed on-stream factor of 67%, this plant can treat 8,132 tons/yr. Based on a preliminary equipment list, it was estimated that it would cost about \$1,300,000 to install the battery-limits equipment. An initial solvent charge would cost about \$15,000. The overall cost of \$173,429/yr for utilities and chemicals reflects the 67% on-stream factor.

Project Economics for the PAB Oil Site

Table B-3 presents the Base Case Economics and 4 sensitivity cases for processing 23,000 tons of PAB Oil Site material having the composition shown above. Costs are based on the EPA's 12 "standard" cost categories presented in Section 4 of the main body of this report. Appropriate comments are given below on the individual cost categories as related to the C-G Process.

The 4 sensitivity cases include:

- case 1. On-stream factor of 0.5 vs. 0.7 in Base Case.
- case 2. \$0/Bbl credit for residual oil vs. \$20/Bbl in Base Case.
- case 3. Capacity of 1.88 tons/hr feed vs. 1.4 tons/hr in Base Case (higher investment, shorter processing time).
- case 4. Capacity of 2.5 tons/hr feed vs. 1.4 tons/hr in Base Case (higher investment, shorter processing time).

There are also two distinctive classifications into which the 12 cost categories fall; technology specific, and site specific. Table B-3 divides the 12 cost categories into these two classifications. While there may be some discussion on which costs are technology and site specific and, in fact, some components of a particular cost category could fall into both for a given technology/project, in this case they have been allocated according to their presentation by the EPA in Section 4 (Table 4-1) of this report.

Technology **Specific** costs are those relating to the particular technology being evaluated and would be incurred while treating the specific feed regardless of where the treatment were taking place. By considering the technology specific costs only, the costs under the control of the technology developer can be itemized and a more valid comparison can be made between competing processes.

Site Specific costs are those relating to a specific site and would be incurred independently of which technology were used for remediation.

The following paragraphs discuss the bases and other considerations of the 12 cost categories included in the evaluation of the C-G process for the SITE Program.

Table B-2. Estimates for Carver-Greenfield Process Plant

Basis

Assumes installation of battery-limits equipment on trailers on September 1991 and operation of plant at a clear and level site in the US. Assumes a conservative 'on-stream factor of 67%. Does not include feed excavation, recovered water treatment, recovered oil disposal, or 'solids storage/Transportation. Initial costs do not include facilities for utility supply.

Initial Costs

Installed Equipment Cost	\$1,300,000
Initial Solvent Charge	\$15,000
Initial Cost	\$1,315,000

Utilities and Chemicals

	Quantities	Unit Costs	Operating Costs		
			\$/hr	\$/ton feed	\$/yr
Steam (250 psig)	1.54 Mil BTU/hr	4 \$/Mil BTU	6.16	4.43	36,159
Power	37 KW	6cents/KWH	2.22	1.60	13,031
Cooling Water	205 gal/min	5 cents/k gal	0.61	0.44	3,610
Makeup Solvent	8.3 gal/hr	1.5 \$/gal	12.45	8.96	73,082
Makeup Nitrogen	1620 SCFH	5 \$/MSCF	8.10	5.83	47,547
			29.55	21.26	173,429

Material Balance (lb/hr)

	Feed	Makeups	Treated Solids	Evap. Water	Recov. oil	Vent
Water	859	0	13	838	0	8
Indigenous Oil	471	0	9	0	462	0
Solids	1441	0	1301	0	140	0
	0	55		1		1
Solvent	0	120		0		120
Total	2771	175	1336	839	642	129

3/2/92

4.2.1. Site Preparation (Site Specific) Costs which include excavation at a cost of \$75.55/hr when operating at design rates was calculated by the EPA (Table 4-1). It is assumed that the quantities handled are relatively small for the equipment required so that the feed for the higher capacity cases can be processed at the higher rates at the same hourly cost as in the Base Case so savings are realized because of the shorter processing time.

4.2.2. Permitting and Regulatory (Site Specific) Costs vary greatly depending on the site and consequently the EPA and DTC have chosen not to include them in this evaluation.

4.2.3. Equipment (Technology Specific) Costs are based on a the capital requirements for the C-G Process unit (1.3 M\$ for the Base Case) and per the EPA should be amortized at 7%/yr over 10 yr, i.e. the equivalent of paying back the principal and interest on a mortgage over a 10-yr period. At the level of plant capacity considered here the investment cost is scaled at the 0.5 power of capacity.

4.2.4. Start-up and Fixed (Technology Specific) Costs are based on estimates of transportation, mobilization, and start-up expenses for the processing unit and are considered based on a one-month time period to accomplish this. The estimated EPA costs of 126 k\$ are used in Table B-3. It is assumed that these costs are independent of capacity so are the same for all cases.

4.2.5. Labor (Technology Specific) Costs are based on DTC manning and labor cost estimates which would require 1 feed operator (\$40/hr, 3 shifts/day), 1 system operator (\$40/hr each, 3 shifts/day), 1 maintenance mechanic (\$40/hr, 1 shift/day), and 1 halftime supervisor (not necessarily onsite; \$60/hr, 1 shift/day). It is projected that the same manning is required for the equipment in the higher capacity cases so that savings are realized in these cases because of the shorter processing times.

4.2.6. Supplies (Technology Specific) Costs for the C-G Process include only the cost of the Isopar-L solvent and since the make-up solvent requirement is calculated based on a per ton of feed basis, the cost is constant at all capacities.

4.2.7. Consumables (Technology Specific) Costs are the utility costs for the C-G plant operation. As, with the supplies category above, since the consumable requirements are calculated on a per ton of feed basis, the cost is constant at all capacities. Note that while the heat requirements are given in terms of steam in Table B-2, EPA has chosen to define the heating medium as natural gas. On this basis it is assumed that natural gas is fired at 75% efficiency to make steam and the heating requirement based on steam has been increased accordingly to reflect this basis on Table B-3.

4.2.8. Effluent Treatment and Disposal (Site Specific) Costs are considered to be insignificant by the EPA and are not included here.

Table B-3. C-G Process- Economic Sensitivity Cases- PAB Oil Site

	Base Case	Case 1	Case 2(1)		Case 3	Case 4	
Feed Tons	23000	230000	23000		23000		23000
On-Stream Factor	0.7	0.5	0.7		0.7		0.7
Design Hourly Rate, Feed Tons/hr	1.4	1.4	1.4		1.88		2.5
Daily Rate, Feed Tons/day	33.6	33.6	33.6		45.12		60
Elapsed time, Days	977.9	1369.1	977.9		730		547
Years	2.68	3.75	2.68		2		1.5
Estimated Investment, \$M	1.3	1.3	1.3		1.51		1.74
Cost Category	Base Case	Base Case					
Site(S)/Technology(T) Specific	Cal Basis	Unit Cost/Basis	\$/Ton Feed				
4.2.1 Site Preparation/S Excavation	75.55 \$/hr	1.4 Tons/hr	53.96	53.96	53.96	40.19	30.22
4.2.2 Permitting and Regulatory/S							
4.2.3 Equipment/T	1.3 M\$	7%/Yr amort 10 Yr life	21.56	30.18	21.56	18.65	16.16
4.2.4 Start-up and Fixed/T	126 k\$	23000 Tons	5.48	5.48	5.48	5.48	5.48
4.2.5 Labor/T							
Feed Operator	1 Operator	40 \$/hr, 3S/D					
Maintenance Mechanic	1 Mechanic	40 \$/hr, 1 s/D					
System Operator	2 Operator	40 \$/hr, 3S/D					
Supervision	0.5 Position	60 \$/hr, 1 WD					
Total			105.44	147.62	105.44	78.52	59.05
4.2.6 Supplies/T, Isopar-L	5.93 gal/ton	1.5 \$/gal	8.90	8.90	8.90	8.90	8.90
4.2.7 Consumables/T							
Cooling Water	8.79 kgal/Ton	0.05 \$/kgal					
Fuel (steam)	1.47 MBtu/Ton	5 \$/MBtu					
Nitrogen	1160 SCF/Ton	5 \$/kSCF					
Electricity	28.6 kwh/Ton	0.06 \$/kwh					
Total			15.31	15.31	15.31	15.31	15.31
4.2.8 Effluent Treatment & Disposal/S			- - -				
4.2.9 Residuals Treatment, etc./S							
Oil	1.56 Bbl/Ton	20 \$/Bbl Credit					
Solids	0.482 Ton/Ton	15 \$/Ton					
Water	72.2 gal/ton	2\$/kgal					
Total			-23.90	-23.90	7.30	-23.90	-23.90
4.2.10 Analyticals/S							
4.2.11 Facility Maintenance/T	1.3M\$	3% Inv/yr	4.54	6.36	4.54	3.93	3.41
4.2.12 Demobilization/S	63 k\$	23000 Tons	2.74	2.74	2.74	2.74	2.74
Total Operating Costs(\$ Ton Feed)			194.03	246.65	225.23	149.82	117.37
Site Specific Operating Cost (\$/Ton Feed)			30.06	30.06	61.26	16.29	6.32
Technology Specific Operating Costs (\$/Ton Feed)			163.97	216.59	163.97	133.53	111.05

(1) Case 2 assumes no credit for Residual Oil safe vs. \$20/Bbl(42 gal) credit in other cases.

4/15/92

4.2.9. Residuals Treatment (Site Specific) Costs although classified as site specific are illustrative of the advantage of the C-G Process technology for this type of site remediation:

The clean water separated using the C-G Process can be processed in a POTW at a cost of \$2.00/\$k gal vs the cost for processing some contaminated waters separately which can be significantly higher.

The clean solids at reduced volume (in this case about 0.5 ton/ton feed) can be landfilled at \$15/ton clean solids or about \$7.50/ton feed vs. contaminated feed material at \$45/ton feed (per EPA) or more depending on its hazardous characteristics (see below).

The separated residual indigenous oil, containing trace amounts of solvent but for the PAB Oil Site containing no

hazardous contaminants, can be sold to an oil refinery for a credit. For the Base Case and 3 Sensitivity cases it was assumed to be sold at a crude oil value of \$20/Bbl (42 gal/Bbl), \$31.20/ton feed, so that the net treatment cost for all the residuals is a credit of \$23.90/ton feed. If the residual oil is disposed of at no cost/no credit (Case 2) the cost of residual treatment is \$7.30/ton feed. Contrast these costs with hazardous materials disposal estimates for incineration at \$200/55 gallon drum used in Table 4-1 which includes \$240/ton of feed for incineration of the indigenous oil alone or \$880/ton (4.4 drums/ton feed) if the total drilling mud waste feed were incinerated.

4.2.10. Analytical (Site Specific) Costs are site specific and for this reason EPA and DTC have chosen not to include them.

4.2.11. Facility Maintenance (Technology Specific) Costs are normally investment related on an annual basis and a typical level of 3% Inv/yr has been chosen by EPA and DTC. These costs vary both with investment level and time required for processing.

4.2.12. Demobilization (Technology Specific) Costs have been proposed by DTC to be about half of the Start-up and Fixed Costs and are shown on this basis in Table B-3.

The following ranges of operating costs are shown on Tables B-3 and 4-1:

	Base Case \$/ton feed	Sensitivity Case Range,	Table 4-1 Base Case
Technology Specific costs	164	111-216	221
Site Specific Costs	30	6-61	302
Total Costs	194	117-247	523

From the above it is concluded that C-G Process technology specific costs are typically in the range of \$100-220/ton of drilling mud waste feed and would be expected to be comparable for similar feeds. Site specific costs, which include the cost of residuals disposal, range from minimal (<\$10/ton) to more than \$300/ton of drilling mud waste feed and in the cases presented here are very sensitive to the assumed residuals disposition and associated costs or credits.

Appendix C

Carver-Greenfield SITE

Demonstration Test Results

This appendix summarizes the Dehydro-Tech Corporation's (DTC) Carver-Greenfield (C-G) Process SITE demonstration. A detailed presentation of the SITE demonstration results can be found in the Technology Evaluation Report. The SITE demonstration was conducted at an EPA research facility in Edison, NJ, using drilling mud wastes from the PAB Oil and Chemical Services (PAB Oil) Superfund site in Abbeville, LA. The waste was transported to EPA's Edison, NJ research facility and was processed over a three-week period. The resulting residuals included concentrated oils, water, and a nonhazardous solids product.

C.1 The PAB Oil Site

The PAB Oil site is located in Vermilion Parish, LA, on about 16.7 acres of property adjacent to Highway 167, north of Abbeville. PAB Oil began operation in 1979 under provisions of a permit issued September 25, 1979, by the Louisiana Department of Natural Resources, Office of Conservation. It received and disposed of oil-field drilling mud wastes and salt water generated from oil and gas well operations.

On July 20, 1980, an amendment to Statewide Order 29-B became effective, establishing new requirements for offsite drilling mud and salt water disposal facilities. Existing facilities were granted temporary authority to operate, with 90 days to comply with the new requirements. PAB Oil reported that it stopped receiving oil-field wastes in August 1982 because of its inability to meet the new requirements. Its interim authority to operate the disposal site was revoked by the Department of Natural Resources on November 10, 1982, and PAB Oil was ordered to proceed with a closure plan for the site. By 1983, the company reportedly lacked the funds for a proper closure. It is now out of business, and the wastes are still on site. The site was placed on the National Priority List (NPL) on March 31, 1989, because of its potential to contaminate the Chicot Aquifer, which is a major source of drinking water in the area (U.S. EPA, 1991).

The material contained in the PAB Oil site pits and surrounding levees is an oily drilling mud which meets DTC's description of a preferred waste type for the SITE demonstration. DTC's SITE proposal indicated the technology could apply to oil-soluble organic contaminants as well as petroleum sludges and petroleum-based oil contaminated soils. In May 1991, about 1,000 kilograms of this material were collected, loaded into drums, and shipped to EPA's Edison, NJ research facility for treatment during the demonstration.

C.2 Description of Operations

Drilling mud waste was stored in drums within a bermed storage area in Building 245 at the EPA facility. Prior to initial system startup, EPA and the SITE team contractor reviewed the Demonstration Plan for the Carver-Greenfield Process (PRC, 1991) with DTC personnel. During startup, the system was checked for problems that would prevent smooth operation of the equipment.

Pilot plant shakedown started the third week of July and continued into early August. Silt and later bentonite were used for the shakedown. Isopar-L was used as the extraction solvent. Several problems were encountered and solved during the shakedown. A gummy material formed when the silt was wetted, plugging some process lines. The upper jacket of the desolventizer leaked, discharging heavy heating oil from the jacket into the solids in the unit. This temporarily interrupted the pilot plant shakedown. The whole system was cleaned and flushed with Isopar-L to remove residues.

In the next shakedown attempt, DTC used a surfactant with the silt to avoid forming the gummy substance during start-up. The shakedown went smoothly, and a dry final product resulted. Laboratory analysis of the final product, using SOW procedures, showed the presence of about 4% indigenous oil. Clean silt was then analyzed by the SOW procedure and was found to be free of indigenous oil. This led to the conclusion that the surfactant was detected as indigenous oil in the SOW procedure. It was decided, based on this conclusion, that surfactant would not be used in either the blank run or waste runs since it could contribute oil contamination to the product solids.

After shakedown was complete, DTC attempted to complete the blank run on July 29, 1991. A silt fraction was used as feed solids instead of sand, as earlier stated in the Demonstration Plan. No surfactant or add-back was used while charging silt to the fluidization tank. Most of the operational changes made for the blank run were implemented by DTC to overcome the difficulties encountered during shakedown.

The blank run was attempted again on August 1, 1991. Operational modifications for this run were preapproved by EPA. Bentonite was used as the solid matrix instead of sand or silt due to its higher water holding capacity and its closer similarity to PAB Oil waste solids. DTC did not use surfactant or add-back while charging the feed in the fluidization tank. The initial blank run also ran into several operational

problems and was canceled. The line between the centrifuge feed tank and the centrifuge became plugged with gummy material. Despite repeated efforts to clear the blockage, the gummy slurry could not be pumped to the centrifuge. The scrubber was also blocked, due to the sticky nature of the slurry.

Although these attempts to start the blank run failed, each attempt provided information which helped optimize operations. In retrospect, the shakedown runs should have used the same feedstock as the blank run. This would have likely prevented the false starts for the blank run.

The SITE demonstration started on August 4, 1991. The initial run was a blank run. Prior to the blank run, no waste feed was admitted to the system. Bentonite was used as the solid matrix since it simulated the waste solids. Blank run samples were collected in accordance with the Demonstration Plan.

Waste feed processing began after the blank run. Two waste feed test runs (Runs 1 and 2), consisting of three extraction steps each were conducted during this phase of the demonstration over two consecutive weeks. During the waste feed runs, samples were collected at various process points. These samples included waste feed, raw solvent, surried feedstock, centrate, centrifuge cake, condensed water, condensed solvent, solids product and vent gas. The number of samples collected at each location, the frequency, and the rationale for sampling and analysis parameters are discussed in Section 3 of the Demonstration Plan (PRC, 1991), as well as in the Technology Evaluation Report (U.S. EPA, 1992). The following briefly discusses each sampling location:

Location 1-Waste Feed: The waste feed was sampled from the cement mixer just before transfer to the fluidization tank. These samples were analyzed for SOW, solvent, TPH, VOC, SVOC, metals, and ignitability.

Location 2-Solvent: The fresh solvent (Isopar-L) was sampled, prior to the blank run, from a randomly selected drum. It was analyzed for solvent, VOC, SVOC, and metals.

Location 3-Slurried Feedstock: The fluidized feedstock/solvent mixture was sampled from the fluidization tank recirculation pump. Samples were taken for each extraction phase. All samples were analyzed for solvent, SOW, and TPH to confirm the ratio of solvent to solids.

Location 4-Centrate: The centrates from each extraction were sampled from the centrate tank. Samples were analyzed for SOW, solvent, VOC, SVOC, and TPH.

Location 5--Centrifuge Cake: Grab samples of the centrifuge cake were taken in each extraction. The samples were analyzed for solvent and SOW.

Locations 6 and 7-Condensed Water/Solvent: During the first extraction, the water was evaporated and condensed. Solvent vapors at this point were also condensed and subsequently collected with condensed water in a single drum. The vapor losses from second and third extractions were also

collected in the drum. The water phase was manually separated from the oil phase using a separatory funnel. Condensed water samples were analyzed for solvent, TPH, VOC, SVOC, metals, and conventional pollutants. Condensed solvent samples were analyzed for solvent, TPH, and metals.

Location 8-Solids Product: The final solids product was collected in a stainless steel drum. The drum contents were mixed before samples were taken. Samples were analyzed for SOW, solvent, TPH, VOC, SVOC, metals, ignitability, and TCLP.

Location 9-Vent Gas: All gases that were not condensed were passed through a granular activated carbon canister that had a measured quantity of carbon. At the end of the full batch run, the canister was opened and samples of activated carbon were taken using a sample thief. Each carbon sample was analyzed for solvent.

C.3 Analytical Results and Discussion

This section discusses the analytical results of the C-G SITE demonstration. First, the feedstock characterization results are discussed. Second, the complete analytical demonstration is presented, including VOC, SVOC, metals, and TPH. Third, indigenous oil removal efficiency is discussed. The next topic discussed is the TCLP results for the final product. Finally, the mass balance of materials during the treatment process is discussed. The Carver-Greenfield Process Technology Evaluation Report (U.S. EPA, 1992) provides a complete presentation of the analytical results.

C.3.1 Feed Characterization

The analyses used to characterize the waste feed included SOW, TPH, solvent, VOC, SVOC and metals. The composition of raw waste feed used in the first and second test run is shown in Table C-1.

The two waste feeds were similar in solids content but differed in indigenous oil and water content. The waste feed in the first test run was lower in water content but had a higher indigenous oil content than the second test run waste feed. The feedstock analyses for Runs 1 and 2 are presented in Tables C-2 and C-3.

In feedstock for Test Run 1 (Table C-2), only xylene was found at detectable levels. Other volatile compounds (toluene and ethylbenzene) and semivolatile compounds (phenanthrene and 2-methyl naphthalene) were found at concentrations less than the method detection limit. In feedstock for Test Run 2 (Table C-3), ethylbenzene and xylene were found at detectable levels while again other volatiles (benzene and toluene) and semivolatiles (phenanthrene, 2-methyl naphthalene, and

Table C-1. Composition of Waste Feeds

Test Run	Solids (%)	Indigenous Oil %	Water (%)
1	52.35	17.47	21.75
2	52.44	7.26	34.7

Table C-2. Carver-Greenfield Process- Test Run 1

Parameters	Units	Feedstock					
		S1	S2	S3	S4	S5	S6
VOC							
toluene	(µg/kg)	585	470	620	545	573	480
ethylbenzene	(wet wt)	883	965	1090	1100	935	983
total xylene (O,m,p)		3480	3710	3870	3730	3500	3660
SVOC - acid extractables							
none	(µg/kg) (wet wt)	All analyses below detectable limits					
SVOC - base neutral extractables							
phenanthrene	(µg/kg)	16700	16300	14000	13700	19200	15800
2-methyl naphthalene	(wet wt)	100000 u	10900	10200	10200	14300	11500
Metals							
aluminum	(µg/g)	11400	10800	11700	10500	10800	8780
barium	(wet wt)	3590	3170	3140	1600	3310	3130
beryllium		0.80	1.06	0.833	0.779	0.76	0.731
boron		47.9	20u	20u	20u	20 u	20 u
cadmium		0.709	0.592	0.576	0.481	0.567	0.545
calcium		2180	2060	2110	2140	2170	2150
chromium		25.6	25.2	26.1	25.7	25.9	24.0
cobalt		7.42	7.07	8.11	7.02	6.98	8.01
copper		16.1	16.2	15.8	17.2	16.5	16.5
iron		13100	14500	13200	14000	13100	13500
lead		39.8	41.8	36.6	41.9	38.1	45.7
magnesium		1510	1520	1560	1540	1610	1360
manganese		365	351	373	347	350	450
nickel		13.9	13.3	13.7	13.1	13.1	12.4
potassium		426	370	532	496	586	497
sodium		140	147	126	128	140	126
strontium		67.8	62.5	67.6	63.0	64.6	61.7
vanadium		24.0	29.1	25.9	23.4	23.3	19.9
zinc		159	154	156	168	163	162
SOW							
solids	(%)	52.67	52.03	51.90	52.70	52.87	51.91
indigenous oil		17.06	17.07	16.96	17.04	18.23	18.52
water		24.21	22.61	20.96	21.30	20.75	20.67
Solvent							
Isopar-L	(%)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
TPH							
total	(µg/g) (wet wt)	155000	137000	138000	143000	165000	143000
Ignitability (°C)		>100	>100	>100	NA	NA	NA
NA - Not analyzed							

NA - Not analyzed

naphthalene) were found at levels less than the detection limit. The major metals in both feedstocks were aluminum, barium, calcium, iron, and magnesium. TPH levels ranged from 80,000 to 150,000 µg/l, confirming the high oil values of the SOW analysis. The feedstock had no detectable Isopar-L solvent and had an ignitability temperature greater than 100 °C.

C.3.2 Summary of the Major Analytical Parameters

The demonstration's primary purpose was to show how well the C-G Process removed indigenous oil from the waste

material. This was assessed by characterizing indigenous oil content using the SOW, TPH and Isopar-L solvent procedures. Tables C-2 and C-3 summarize analytical results for the two test runs.

C.3.3 Characterization of Oil Removal Efficiency

The efficiency of the C-G Process for the PAB Oil SITE demonstration was based strictly on its ability to remove indigenous oil. Indigenous oil removal is based on the results of the SOW, TPH, and solvent analytical procedures. The indigenous oil result determined in the SOW procedure

Table C-3. Carver-Greenfield Process- Test Run 2

		Feedstock					
Parameters	Units	S1	S2	S3	S4	S5	S6
VOC							
-benzene	(µg/kg)	1250 U	688	1250 U	1250 U	7250 U	766
toluene	(wet wt)	763	803	1150	1130	1210	1220
ethylbenzene		1860	1960	2060	1510	2140	1790
total xylene (0,m,p)		8820	9000	9270	7870	10000	8280
SVOC - acid extractables							
none	(µg/kg) (wet wt)	All analyses below detectable limits					
SVOC - base neutral extractables							
phenanthrene	(µg/kg)	11000	11500	12100	1090	1070	12000
2-me thyl naphtha/ens	(wet wt)	45500	50900	55800	36600	48800	57300
naphthalene		50000 U	17600	17500	50000 U	16200	19200
Metals							
aluminum	(µg/g)	7380	7150	7100	7230	7610	7640
barium	(wet wt)	653	688	666	450	520	478
beryllium		0.65	0.63	0.73	0.79	0.74	0.68
boron		31.6	20.0	20.0	20.0	20.0	20.0
cadmium		3.90	4.10	4.07	4.01	3.82	4.72
calcium		8000	7630	7570	7980	7840	7690
chromium		140	136	137	140	141	141
cobalt		9.15	8.89	10.0	9.54	9.33	9.52
copper		83.8	87.2	87.8	93.7	92.2	86.3
iron		20000	19300	19700	25500	19800	20100
lead		207	196	208	205	213	202
magnesium		1260	1190	1230	1300	1260	1270
manganese		266	264	284	285	276	281
molybdenum		23.8	24.8	26.4	26.8	25.6	24.7
nickel		20.6	19.7	19.7	20.7	21.9	22.4
potassium		711	726	707	778	785	76
sodium		609	579	597	622	607	581
strontium		261	236	279	286	298	264
vanadium		21.5	20.8	22.6	22.2	22.4	22.7
zinc		1000	1030	990	1030	1020	1010
SOW							
solids	(%)	52.31	53.00	52.69	52.06	52.08	52.50
indigenous oil		7.37	7.78	7.05	6.51	7.69	7.03
water		36.62	34.95	34.07	34.74	33.63	34.61
Solvent							
Isopar-L	(%)	<0.1	<0.1	<0.1	<0.1	<0.1	0.10
TPH							
total	(µg/g)	79200	78600	94900	82500	103000	98100
Ignitability (°C)							
		>100	>100	>100	NA	NA	NA

NA - Not analyzed

Table C-4. Oil Parameters for Feedstock and Final Product

	SOW			TPH (%)	Isopar-L		Calculated Oil		
	Solids (%)	Oil (%)	Water (%)		As Solvent (%)	As TPH (%)	Indigenous Oil	Indigenous TPH	Non-TPHs Oil
Test Run 1									
Feedstock	52.35	1748	21.75	14.7	0	0	17.47	14.7	2.77
Final Product	96.56	1.38	0	0.79	0.93	0.84	1.38	0	1.38
Test Run 2									
Feedstock	52.44	7.24	34.7	8.9	0	0	7.24	8.9	
Final Product	98.31	0.85	0	0.66	0.99	0.89	0.85	0	0.85

Table C-5. Oil Removal Efficiency Percent Removal

	True indigenous oil	indigenous TPH
Test Run 1	92.1,	100
Test Run 2	69.3	100

Table C-6. Toxicity Characteristic Regulatory Limits and TCLP Results from Test Run 1 Treated Solids

Parameters	Regulatory Limits (mg/l)	Average Biased (mg/l)	Average Unbiased (mg/l)	Average Recovery (%)
VOC				
benzene	0.5	0.05U	0.05U	97.00
carbon tetrachloride	0.5	0.05U	0.05U	96.33
chlorobenzene	100.0	0.05U	0.05U	96.67
chloroform	6.0	0.05U	0.05U	97.00
1,2-dichloroethane	0.5	0.05U	0.05 U	96.67
1,1-dichloroethene	0.7	0.05U	0.05 U	97.00
methyl ethyl ketone	200.0	0.10U	0.10U	75.33
tetrachloroethene	0.7	0.05U	0.05U	95.00
trichloroethene	0.5	0.05U	0.05 U	94.00
vinyl chloride	0.2	0.05U	0.05U	99.00
SVOC - acid extractables				
m+p-cresol	100.0	0.10U	0.10U	35.00
o-cresol	(combined)	0.10U	0.10U	40.33
pentachlorophenol	100.0	0.20 U	0.20 U	64.67
2,4,5-trichlorophenol	400.0	0.10U	0.10U	53.67
2,4,6-trichlorophenol	2.0	0.10U	0.10U	56.67
SVOC - base neutral extractables				
1,4-dichlorobenzene	7.5	0.05 U	0.05U	44.00
2,4-dinitrotoluene	0.13	0.05U	0.05 U	55.00
hexachlorobenzene	0.13	0.05 U	0.05u	55.00
hexachloroethane	3.0	0.05 U	0.05U	42.33
nitrobenzene	2.0	0.05 U	0.05U	57.00
pyridine	5.0	0.10 u	0.10U	30.67
hexachloro-1,3-butadiene	0.5	0.05 u	0.05u	42.33
Metals				
arsenic	5.0	0.50 U	0.50 U	106.33
barium	100.0	1.16	1.17	100.33
cadmium	1.0	0.10U	0.10U	106.67
chromium	5.0	0.10U	0.10U	105.67
lead	5.0	0.10U	0.10U	105.00
mercury	0.2	0.002 U	0.002 U	66.33
selenium	1.0	0.50U	0.50 U	100.33
silver	5.0	<0.152	<0.130	81.00

U - indicates compound was analyzed for but was not observed at quantifiable concentrations

Biased values incorporate compound-specific matrix interferences detected by spike analysis for each regulated compound

cludes a broad range of organics soluble in toluene. Petroleum hydrocarbons, as well as other polar and nonpolar organics are detected in the SOW procedure. The TPH procedure detects only nonpolar organics, which includes the Isopar-L solvent. The solvent procedure uses gas chromatography and detects only the Isopar-L solvent. This overlapping nature of the SOW, TPH, and solvent procedures makes it difficult to determine true indigenous oil removal directly.

The indigenous oil fraction of the SOW procedure for the feed stock and final products represents those oils that originate solely from the waste material. Because TPH, which is a widely used parameter for regulating land application of sludges, soil contamination and fill suitability, detects the Isopar-L solvent, the only way to estimate indigenous TPH in the product solids is to subtract the Isopar-L solvent result from the TPH result.

Table C-7. Toxicity Characteristic Regulatory Limits and TCLP Results from Test Run 2 Treated Solids

Parameters	Regulatory Limits (mg/l)	Average Biased (mg/l)	Average Unbiased (mg/l)	Average Recovery (%)
VOC				
benzene	0.5	0.05U	0.05u	94.67
carbon tetrachloride	0.5	0.05U	0.05u	93.00
chlorobenzene	100.0	0.05U	0.05u	94.67
chloroform	6.0	0.05U	0.05U	96.33
1,2-dichloroethane	0.5	0.05 U	0.05u	96.33
1,1-dichloroethene	0.7	0.05U	0.05 U	100.67
methylethyl ketone	200.0	0.10U	0.10U	87.33
tetrachloroethene	0.7	0.05U	0.05U	95.00
trichloroethene	0.5	0.05U	0.05u	93.67
vinyl chloride	0.2	0.20 U	0.20U	98.67
SVGC - acid extractables				
m+p-cresol	100.0	0.10U	0.10U	37.00
o-cresol	(combined)	0.10U	0.10U	44.00
pentachlorophenol	100.0	0.20 u	0.20 u	91.00
2,4,5-trichlorophenol	400.0	0.10U	0.10U	61.00
2,4,6-trichlorophenol	2.0	0.10U	0.10U	67.00
SVOC - base neutral extractables				
1,4-dichlorobenzene	7.5	0.05u	0.05u	47.00
2,4-dinitrotoluene	0.13	0.05u	0.05U	55.00
hexachlorobenzene	0.13	0.05u	0.05 U	59.00
hexachloroethane	3.0	0.05 U	0.05 U	45.00
nitrobenzene	2.0	0.05U	0.05u	54.00
pyridine	5.0	0.10U	0.10U	27.00
hexachloro-1,3-butadiene	0.5	0.05u	0.05u	46.00
Metals				
arsenic	5.0	0.5 u	0.5 u	91.67
barium	100.0	3.44	2.91	85.00
cadmium	1.0	0.10U	0.10U	84.33
chromium	5.0	0.10U	0.10U	84.00
lead	5.0	0.10U	0.10U	86.33
mercury	0.2	0.002 u	0.002 u	55.67
selenium	1.0	0.50 U	0.50 u	82.67
silver	5.0	0.10U	0.10U	61.33

U - indicates compound was analyzed for but was not observed at quantifiable concentrations

Biased values incorporate compound-specific matrix interferences detected by spike analysis for each regulated compound

Table C-4 summarizes the relevant oil parameters for feedstock and final product samples from both test runs. The calculated oil values denoted as “true indigenous oil” and “indigenous TPH” are derived as previously discussed. The difference between these two values is oil not detected by the TPH procedure. Non-TPH indigenous oil ranged from 0.85% in Test Run 2 to 1.28% in Test Run 1. Table C-5 shows oil removal efficiency for both test runs based on the results in Table C-4.

This approach qualitatively characterizes oil removal. This is because quantifying oil removal is difficult due to the overlapping nature of the analyses. Final product TPH or oil by the SOW procedure can be directly determined if this is the objective. If, however, the objective is to remove the oil indigenous to the waste, understanding of the analytical methods and calculation involving the results of these methods is necessary. Tables C-4 and C-5 reflect this method of oil removal characterization.

While the final product TPH ranged from 0.66% to 0.79% in both test runs, no indigenous TPH was detected in both final products. Final product indigenous oil by the SOW procedure ranged from 0.85% to 1.38%. Using the calculated true indigenous oil and indigenous TPH values, indigenous oil removal ranges from 88% to 100%.

C.3.4 TCLP Results

The raw pit waste sample from PAB Oil Site was collected in November 1990 to characterize the waste for the demonstration and was analyzed by TCLP. The waste sample passed TCLP, and therefore was not a RCRA-characteristic waste.

TCLP tests were performed on the treated solids product of Test Runs 1 and 2. Tables C-6 and C-7 present the results for Test Runs 1 and 2, respectively. These tables also include the appropriate RCRA regulatory criteria. The results indi-

cate that the treated solids product in test runs 1 and 2 was not a RCRA-characteristic waste.

C.3.5 Mass ***Balance***

A mass balance was performed on the C-G Process using materials inventory data (total waste feed, solids, water and indigenous oil phases) for each test run. Mass balancing accounts for components of the waste feed and other process inputs as compared to products and residuals. Mass balance closure determines the amount of each constituent in the waste feed and other inputs which can be accounted for in the products and waste streams of the process. A gross mass balance accounts for only the major components **such as** solids, soil and water. Detailed mass balances account for other components, such as organics and metals.

A gross mass balance performed on the C-G Process showed about 96.2% combined recovery of all the constituents for Test Run 1, and a 96.4% recovery for Test Run 2. On a

constituent basis, 81.2% solids, 112.2% water and 97.3% oil phases were recovered in Test Run 1. Similarly, 78.9% solids, 95.8% water and 98.3% oil phases were recovered in Test Run 2. A detailed mass balance of the C-G Process is discussed in the Carver-Greenfield Process Technology Evaluation Report (U.S. EPA, 1992).

References

PRC, 1991. Demonstration Plan for the Carver-Greenfield SITE Demonstration Program Report (June).

U.S. Environmental Protection Agency (U.S. EPA), 1991. Data Summary Report, PAR Oil and Chemical Services Superfund Site, Vermilion Parish, Louisiana.

U.S. EPA, 1992. Technology Evaluation Report. SITE Program Demonstration of the Dehydro-Tech Corporation's Carver-Greenfield Process, EPA/540/XX-92/XXXX (to be published).

Appendix D

Carver-Greenfield Process Case Studies

Note: This appendix to EPA's Applications Analysis Report was prepared by Dehydro-Tech Corporation (DTC). Claims and interpretations of results in this Appendix are those made by the vendor and are not necessarily substantiated by test or cost data. Many of DTC's claims regarding cost and performance can be compared to the available data in Section 4 and Appendix C of the Applications Analysis Report.

This appendix summarizes case studies on the Carver-Greenfield Process. The following case studies are covered:

Case Study	Description
D-1	Refinery Slop Oil from Northeast U.S.
D-2	Petroleum Sludge from East Coast Refinery
D-3	Wool Scouring Waste at Burlington Industries

Case Study D-1

Material Processed Refinery Slop Oil

An oil refinery "slop oil" containing 12 weight percent solids and 72 weight percent water from a wastewater pond in the Northeast was processed by DTC for treatability evaluation and plant design guidance. This material was separated into its solid, water, and indigenous oil fractions in DTC's stationary pilot plant. The equipment used in the stationary pilot plant is similar in design and operation to that of the mobile pilot plant used for the SITE demonstration.

A 39.2-lb charge of slop oil sample was slurried with 80 pounds of a narrow boiling paraffinic solvent (boiling point = 370 to 380 °F), to which had been added about 0.4 lb of a surfactant to aid suspension, and pumped around in a forced-circulation evaporation system. Water was evaporated at the rate of 35 to 45 lb/hr at 11 in. of Hg vacuum and 180 to 235 °F until there was less than 1 weight percent water on the solids product. The dried slurry was cooled and centrifuged batchwise in a Fletcher centrifuge with a perforated bowl at 1200 G force. The centrifuge cake contained about 48 weight percent solids, 4.6 weight percent indigenous oil, and 47 weight percent solvent.

The centrifuge cake was split into two samples. Sample 1 was solvent extracted once. Sample 2 was solvent extracted twice. These solid samples were deoiled in a vacuum oven at 300 °F and 29 in. of Hg vacuum. After deoiling, the solid samples contained 2 weight percent and 0.2 weight percent

indigenous oil and less than 0.1 weight percent solvent, as shown in Table D-1.

The pH of the feed slop oil was 7.3 and that of the water condensate 6.0.

The forced circulation evaporation system was charged with 104 pounds of a solvent/indigenous oil mixture and the solvent was evaporated at about 250 °F and 26 in. Hg vacuum. Steam was added to assist stripping at the end of the run which produced an indigenous oil product with less than 0.8 weight percent solvent.

According to the refiner, the original slop oil was unsuitable for landfilling due to the presence of a variety of compounds. The Rocky Mountain Laboratory in Boulder, CO tested the dry solids after treatment in the C-G Process and determined that **both** samples met all the prevailing requirements for non-hazardous landfilling as specified by the EPA.

Sufficient process and design data was developed from the above testing to design a commercial unit to process this slop oil.

Table D-1. Sample Composition

Component	Slop Oil (weight %)	Fresh Slurry (weight %)	Solids (weight %)	
			Sample 1	Sample 2
Solids	12.0	3.9	97.8	99.6
indigenous	16.0	5.3	2.0	0.2
Hydrocarbons				
Water	72.0	23.7	<0.1	<0.1
Solvent	0.0	67.1	<0.1	(0.1
Total	100.0	100.0	100.0	100.0

Case Study D-2

Material Processed: Petroleum Sludge

A major refinery on the U.S. East Coast furnished the following samples to DTC: DAF sludge, API separator bottoms, tank bottoms, bio sludge, and primary/secondary emulsions. These materials were mixed together in different proportions to produce three feeds for treatability testing in DTC's stationary pilot plant.

About 90 lb of each feed was charged to and pumped around in a forced-circulation evaporator system. During

circulation the feed was heated and the solids dried by evaporating the water present. Two stages of evaporation were simulated. The feed compositions and operating conditions for drying are listed in Table D-2.

During the water evaporation approximately 12 weight percent of the indigenous oil in the feed was vaporized and condensed with the water.

The dry slurry was centrifuged while hot in a Fletcher basket centrifuge using a solid bowl at 1200 G force. The collected solids were reslurried in a narrow boiling solvent (BP = 370 to 380 °F) and filtered using a Buchner funnel. The filter cake solids were deoiled in a vacuum oven at about 250 °F and 28 in. of Hg vacuum.

The deoiled product solids properties are listed in Table D-3.

Although the solids recovered were very fine, all the feed mixtures were processed without difficulty. This case showed that starting with feed materials having a high indigenous oil to solids ratio (in the range of 25 to 40), the C-G Process was able to produce solids containing only 3.8% to 5.4% indigenous oil. Lower levels could be achieved, if required, by further extractions with a suitable solvent. The refinery advised DTC that the hazardous compounds present in the original feed materials, such as benzene and phenol, had been effectively extracted from the solids.

Sufficient process and design data was developed from the above testing to design a commercial plant

Case Study D-3

Material Processed: Wool Scouring Waste

Table D-2. Feed Compositions

Feed Materials	Feed Mix A	Feed Mix B	Feed Mix C
OAF Sludge	26.5%	26.5%	26.5%
API Separator Bottoms	—	—	2.9
Tank Bottoms	—	12.3	—
Bio Sludge	10.2	10.2	11.3
Emulsions	63.3	51.0	56.4
Total	100.0%	100.0%	100.0%
Feed Components			
Solids	1.5%	1.6%	2.1%
Water	44.0	35.2	44.7
Indigenous Oil	57.6	63.8	53.2
Total	103.1%	99.6%	100.0%
Operating Conditions			
First Stage			
Temperature, °F	150	152	152
Vacuum, inches Hg	23.0	23.0	23.1
H ₂ O Evaporated, lb/hr	33.8	27.8	30.2
Condensate p H	9.0	8-9	8-9
Second Stage			
Temperature, °F	197	198	201
Vacuum, inches Hg	12.0	11.0	11.8
H ₂ O Evaporated, lb/hr	30.0	30.2	32.0
Condensate pH	5.0	5-6	5-6

A number of samples of wool scouring waste and industrial activated sludge from the Burlington Industries, Clarksville, VA plant was furnished to DTC for treatability testing in DTC's stationary pilot plant. The processing objectives were twofold: to treat the waste streams suitably for discharge to the environment and to extract lanolin as a valued by-product from the oil in the wool scouring waste.

The ranges of composition of each feed which were processed separately and in mixtures in the pilot plant were:

The ratio of wool scouring waste to activated sludge to be processed together was about 18 to 1.

Numerous pilot plant runs were made to determine the optimum processing scheme for these materials on a commercial scale. Formulation of the design basis for the scale-up included determining:

- the required number of evaporation stages for efficiently removing the high quantity of water present in the wool scouring waste,
- the optimum stage for adding a hydrocarbon solvent to minimize solids deposition and to permit the water evaporation to be completed,
- the appropriate stage to add the activated sludge to the wool scouring waste being processed, and
- the optimum processing conditions for recovery of lanolin.

Based on the results of the pilot plant work, a commercial plant was designed and installed at the Burlington Industries facility in Clarksville, VA for the following combination of feeds:

The commercial plant, started up in 1985, includes an energy efficient five-stage multi-effect evaporation system, centrifuge, a three-stage solids deoiling system, an acidification system, evaporation facilities for solvent recycle, and a solvent stripping unit for product lanolin recovery. The recovered product water is discharged to a waste treatment facility and the solids are incinerated.

The original design anticipated fluidizing the wool scouring waste in a narrow-cut paraffinic solvent and feeding it to the first four evaporator effects operating at 120, 140, 160, and 180 °F, respectively. The fourth stage product would be acidified and mixed with the remaining solvent and the activated sludge and fed to the fifth stage which operated at 260 °F.

Table D-3. Deoiled Product Solids Properties

	Feed Mix A	Feed Mix B	Feed Mix C
Solids	95.5%	96.0%	94.4%
Water	<0.1	<0.1	<0.1
Indigenous Oil	4.3	3.8	5.4
Solvent	<0.1	<0.1	<0.1
Total	100.0%	100.0%	100.0

Table D-4. Wool Scouring Waste Composition

	<u>Activated Sludge</u>	<u>Wool Scouring Waste</u>
Water, wt%	83.5-85.1	94.4-98.8
Solids, wt%	12.7-15.8	0.7-3.4
oil, wt%	1.8-2.2	0.6-2.2
PH	6.0-6.5	6.1-8.1

Table D-5. Commercial Plant Feed Composition

	<u>Activated Sludge</u>		<u>Wool scouring Waste</u>	
	<u>Composition</u>	<u>Flow Rate</u>	<u>Composition</u>	<u>Flow Rate</u>
	(wt%)	(lb/hr)	(wt%)	(lb/hr)
Water	85.0	1,880	94.4	37,600
Solids	12.8	283	3.4	1,342
oil	2.2	50	2.2	880
Total	100.0	2,213	100.0	39,822

Subsequent to start-up, the expected feed analysis of the wool scouring waste became less than 1.5 weight percent solids and less than 1 weight percent oil (versus design values of 3.4 and 2.2 weight percent, respectively). Equipment modifications were made to accommodate this change and presently the evaporation of water from the wool scouring waste takes place without solvent present in the first three stages of the evaporator. Solvent is added to the fourth and fifth stages and activated sludge is added to the fifth stage. During typical operations product solids contain an average of 0.6 weight percent water and 0.9 weight percent solvent. Solvent is not detected in the effluent water condensate. Steam consumption is about 0.3 lb of steam per lb of water evaporated.

The unit has been operating reliably since 1985.